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STUDY MATERIAL

for

WELL WATER SYSTEMS

Department of Health and Environmental Sciences
Water Quality Bureau
Room A206 Cogswell Building
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INTRODUCTION

A reliable water supply is one of the most important elements of a community. Not only must sufficient quantities of water be available, but the water must also be safe for human consumption. A water system operator is responsible to see that both are accomplished.

The Water Quality Bureau of the Montana Department of Health and Environmental Sciences presents this study material as a certification examination reference for well water system operators. But it is hoped that the material will also be used as a reference guide to assist the operator in the able performance of his duties.

The material contained in this booklet is presently under revision and additional information will become available at a later date.

It is recommended that operators read additional reference materials in preparation for the certification examination. Highly recommended is SMALL WATER SYSTEMS SERVING THE PUBLIC available from Montana Rural Water Systems, Inc., 1824 Tenth Avenue South, Suite 4B, Great Falls, Montana, 59405. The cost is $2.50. The publications available from AWWA, 6666 Quincy Avenue, Denver, Colorado, are also excellent sources of information.

February, 1982

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SECTION 1

USING GROUNDWATER FOR PUBLIC WATER SUPPLIES

Groundwater is widely used in Montana as a source of water for many public water supplies. Groundwater has a number of advantages, two of which are:

1. Groundwater has a low pollution probability.

2. Groundwater may be available where surface waters are not.

There are also a number of disadvantages in using groundwater for public water supplies including:

1. The longevity of wells is variable but as a general rule, wells tend to fail sooner than adequately designed surface water supplies.

2. Pumping costs of well systems can be a very significant cost factor for public water supply.

3. Wells water normally contains more dissolved minerals than does surface water.

4. Wells that become polluted are difficult and expensive to correct and often have to be abandoned.

Before discussing groundwater for public supplies, the basic concepts of groundwater hydrology should be reviewed.

Basic Groundwater Concepts

Wells obtain their water from those portions of the earth's strata called aquifers. Aquifers are strata that will store and transmit significant quantities of water. Generally, we consider any layer to be an aquifer that will yield water to wells. Aquifers have both a vertical and a horizontal extent. Commonly, the aquifer consists of a layer of unconsolidated sand and gravel that has a wide horizontal extent. The aquifer also may be a bedrock layer that has groundwater in fractures or openings.

Generally, aquifers can be classed as sedimentary, igneous, or metamorphic in their origin. This refers to the type of geologic material that constitutes the aquifer. Sedimentary rocks include the following important types of deposits:

1. Alluvial deposits such as stream deposits, glacial drift, lake deposits, etc.

2. Consolidated rocks or bedrock such as sandstones, limestones, shales, etc.

Igneous rocks consist of hard crystalline rocks of which granite is a typical rock type. Igneous rocks also include volcanic flow rocks (lavas)

which would include such rocks as basalt, andacite, and dacite. Metamorphic rocks are those rocks that have undergone substantial heat and pressure and have changed their form. Typical types of metamorphic rocks are schist and gneiss.

Where does groundwater come from? Almost all groundwater that is utilized by public water supplies had its origin at some time in the past as a precipitation on the earth, either snow or rainfall. This moisture has percolated into the ground and moved downward and laterally into the aquifers. Since water is constantly on the move in these aquifers, it is a perpetually moving, ever-changing system. Groundwater moves very, very slowly, and it may take many years or many thousands of years for groundwater to move long distances laterally in an aquifer. The dominant and most unusual characteristic of groundwater is its very slow movement.

There are two general types of aquifers, confined and unconfined. Confined aquifers, typically called artesian aquifers, generally contain water that is under pressure greater than atmospheric, and are confined between impermeable strata. Typically, this would be a sandstone layer that is confined both top and bottom by a shale. If the confining pressure is great enough, the wells may flow and are termed flowing artesian aquifers. Unconfined aquifers, commonly called water table aquifers, are not confined by an upper layer, but are essentially at atmospheric pressure. In unconfined aquifers, the water does not rise into a well after the water bearing zone is penetrated during drilling. Typically, unconfined aquifers are shallow, unconsolidated sedimentary materials composed of sands and gravels or other coarse materials. Confined aquifers generally consist of deeper lying, horizontally stratified layers such as sandstone or limestone.

There are substantial differences between confined and unconfined aquifers in their response to development for groundwater supplies. Confined aquifers tend to have a smaller amount of water in storage per unit volume than do unconfined aquifers. Confined aquifers also respond very rapidly and very widely to pressure changes caused by pumping. Pumping, of course, tends to lower aquifer pressures immediately around the pumped well; this pressure change is transmitted very rapidly and to a long distance in confined aquifers. In unconfined aquifers, pumping also lowers pressures in the aquifer adjacent to the well; however, the pressure effects are much more localized than pressure effects due to pumping confined aquifers.

A term that is widely used in groundwater discussions is permeability--the ability of water to move through a geological material. This is a function of the pore space, particle size, and arrangement and continuity of pores. Strata having high permeabilities allow water to move relatively freely, whereas strata with low permeabilities allow groundwater to move only very slowly through the aquifer.

Groundwater flows toward a well in response to pumping. When a well is pumped, groundwater flows toward the well and water is removed from the aquifer surrounding the well. A cone of lowered pressure or a cone of depression is created around the well. This cone represents the area of the aquifer that is influenced by the pumping of the well. When pumping starts, water comes from the aquifer nearest the well; as pumping continues,

the cone of depression extends to meet the increased water needs. The cone continues to expand and deepen until it intersects some natural source of water recharge such as a stream or other water body. The cone then stabilizes, sometimes requiring hours or even years to do so.

Development of Groundwater Supplies

There are several important factors that must be considered in the development of a groundwater supply, including the water needs of the community, the location of the wells, the design and construction of the wells, and the well operation. These factors determine the successfulness and costs of a public water supply.

Water Needs

For many communities, there is an increasing demand for water due to higher per capita consumption and increasing population. Commonly, a study is needed to determine the existing water needs and the future water needs that the community will experience based on the trends in population and consumption per capita. In such a water-needs survey, usually an inventory of the existing water supplies is described, including wells and surface water supplies and the location of water transmission and storage facilities. Water consumption also must be examined to determine average and peak use rates. If additional water supplies are needed, the ability of groundwater or surface water supplies to provide for this additional need are examined. Should expansion of a public water supply become necessary, the source that will provide both the quality and quantity desired at a minimum expense will be used.

Well Location

An important step in the development of a groundwater supply is location of a new well. Several factors should be considered:

1. Favorable geological conditions must be found to supply groundwater to the well. This requires a knowledge of geology, groundwater hydrology, and an examination of existing well logs and groundwater data from the area. Generally, a groundwater study of an area will be required to insure proper location of wells with respect to water-bearing formations. The well must produce adequate quantities of good quality water.

2. All groundwater withdrawal points should be located a safe distance from sources of pollutions. Sources of pollution include septic tanks, sewers and sewage treatment facilities, industrial waste discharges, land drainage, farm animals, fertilizers, and pesticides. A safe distance is the distance that ensures no contamination will be drawn or will flow to the withdrawal point. Because many factors affect the determination of a safe distance, it is impractical to set fixed distances, but the following minimum distances are recommended:

Cesspool receiving raw sewage	100 feet
Seepage pit or drainfield	100 feet
Septic tank	50 feet
Cast iron sewer line	10 feet

3. A well should be located on the highest ground practicable and the site should allow for adequate drainage. It should certainly be on ground higher than nearby sources of pollution.

4. The availability of land and power must be investigated.

Design and Construction

The next step in development of a public water supply is test drilling of geologic strata and pumping for potential water yields. Based upon this test, a production well can be designed. The depth, diameter, and material for construction are then selected. Such things as well screens, slots, and gravel packs are chosen at this time. A pump can be selected based upon a pump test to determine the water yield of the production well. It is important to select a pump having good efficiency so that the water can be produced at the least cost.

All wells must be properly sealed against water contamination. Groundwater can be contaminated by surface water entering through the top of the well or by water from contaminated aquifers flowing down the outside of the well casing to the intake point. Proper grouting procedures must be used to seal the wells from any contaminated aquifers. Well casing must extend a minimum of 18 inches above ground level or two feet above flood elevation. Vents necessary to maintain atmospheric pressure in the casing and prevent the occurrence of back siphonage should be screened (#24 MESH) with the return bend facing downward. The screened end of the vent should terminate at least 18 inches above ground or above the maximum flood level, whichever is higher. The well must be disinfected after drilling and equipping with pumps, piping, etc. Samples should be taken to determine the bacteriological quality of the water.

A sanitary underground discharge assembly, popularly called a pitless adapter, provides the most practical solution to the sanitary completion of the upper part of a well when a submersible pump is used. The pitless device extends the well casing above ground and provides water-tight subsurface connections for buried pipe discharge or suction lines. These pipes should be buried below the frost line to avoid freezing. Until the development of the pitless adapter, installing pumps in pits below ground level was almost a universal practice where frost protection for piping was required. Pump pits are always unsanitary, and the pitless unit provides a practical means of doing away with them. Another advantage of the pitless unit is that the pump may be removed from the well for repair or replacement without disturbing the underground discharge pipe.

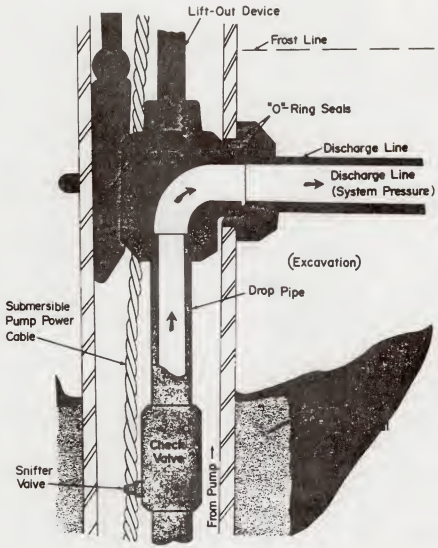


Figure 1. Clamp-on pitless adapter for submersible pump installation

Well Operation and Associated Problems

Proper operation of wells is equally important to proper location and construction. Well systems are typically not carefully examined until some problems have caused the well to fail to produce water of an adequate quality or quantity. The well, like any other mechanical system, should be inspected periodically and tested to insure that it is performing properly and that no problems are beginning to appear. The quality of the water should be constantly monitored and the performance of the well, particularly the efficiency of the wells and pump, should be checked.

The cost of well construction and the equipment for wells is increasing very rapidly; thus, extending the useful life of a well is of more interest than ever. There is a tendency to assume that an old well that is not functioning properly should be replaced by a new well, but it is important to give the old well a thorough examination before it is pronounced dead. It is also important to check the health of your community's "good wells" as well as those wells that are bad. The operator must develop a preventative maintenance program for existing community wells.

A problem that may confront the operator of a groundwater supply is a steadily declining yield of water from a well. This can be caused by several factors including problems with the well itself or problems with the pumping equipment. One of the first things that should be examined is the record of groundwater levels in the well. If groundwater levels in the area of the well have continuously declined, this may be the reason that production from the well has declined. This may be due to an overall lowering of water tables in the vicinity of the well and is difficult if not impossible to correct. Correction of such a problem normally requires deepening of the well or drilling of a new well. If general water levels in the area have not declined significantly and the well is declining in production, then the problem will probably be with the pumping equipment in the well. This can be due to pump wear, problems with electrical service or clogging of the pump inlet. Correction, except for possibly electrical service, requires pulling the pump for examination and repair.

Another factor that may cause declining yields is the problem of clogging of the water intake portion of the well. Typically the water enters a well through slots or screens. These may be clogged due to corrosion and incrustation. Incrustation leads to accumulations of materials on the well casing, particularly in the intake portions. Lime is the most common incrustation material although it can also be due to oxides, hydroxides and carbonates of other metals. Clay, sand, or silt can also plug well intake sections and bacteria can form coatings that will plug intakes. A plugged intake will not allow water to flow freely into the well. Such plugging problems can often be corrected by rehabilitation programs that include surging of the well, hydraulic jetting, explosives, acidizing, and dry ice. The rehabilitation of a plugged well requires the advice and skill of experienced well personnel. Bacterial sludges and slimes that plug wells can be cleared by the treatments described above but will also require a strong disinfectant to inhibit or kill their growth. Complete disinfection of a well is difficult, and the presence of iron bacteria may be quite persistent.

Another cause of reduced water yields from wells is sand. Sand may bridge the openings surrounding the intake section of a well and reduce the movement of water from the aquifer into the well. Sanding problems can be caused by improper selection of gravel pack, improper slot size or screen size, and inadequate well development after drilling. Redevelopment may be necessary to correct a sanding problem.

Occasionally a well casing may collapse leading to total failure of the well. This is usually caused by corrosion of the metal well casing causing a structural weakness. Most metal corrosion is of two types:

1. Chemical corrosion due to corrosive conditions either internally caused by the water or externally caused by soil conditions (pH of the water, dissolved oxygen, hydrogen sulfide, carbon dioxide, dissolved salts, and temperature).

2. Galvanic corrosion caused by electrical currents generated by two different metals in contact.

Sulfate reducing bacteria and iron oxidizing bacteria can also produce corrosive conditions. Severe chemical corrosive conditions may require corrosive resistant materials. Galvanic corrosion may be prevented by making certain that similar metals are used throughout.

To reiterate, corrosion limits well life by:

1. Allowing screen openings to enlarge.

2. Reducing the strength of the casing.

3. Allowing for a buildup of the products of corrosion resulting in incrustation.

In reviewing, remember that several problems can occur that will cause an inadequate or declining yield from a well:

1. Worn pump impellers.

2. Poor electrical connections.

3. Over pumping.

4. Clogging of the intakes in the well by sand.

5. A declining water table.

6. Incrustation or corrosion.

Wells may have to be removed from service due to water quality problems. Bacteriological or chemical conditions within the wells may be unsuitable or may become unsuitable due to a combination of circumstances. Bacterial contamination is not uncommon in public water supply wells. Groundwater,

however, is a hostile environment for bacteria and is not favorable for the reproduction and growth of these bacteria. Almost all bacterial pollution involving coliforms is caused by entry of outside water into the well top. Other types of bacterial pollution include iron and sulfate bacteria, both mentioned previously. The most important factor in bacterial pollution is the proper construction and design of the well to exclude polluting waters from entering the well.

A possible solution to wells that become contaminated with bacteria is chlorination or another type of disinfection. Coliform bacteria respond well to chlorination; however, sulfur and iron bacteria do not respond as well. Commonly wells polluted with iron and sulfur bacteria must be rechlorinated frequently to keep the water pure. Other types of pollutants in wells include a great variety of organic and inorganic compounds including petroleum products, pesticides, metal-bearing wastes, and dissolved minerals. Some of these pollutants are very difficult or impossible to correct; some are not. Well siting is the best preventative for this problem. Specific corrections to pollution problems depend on the type of pollutant and its susceptibility to abatement, treatment or elimination. Instructions for chlorinating wells are given in Section IV, Chlorination.

Another type of pollution problem is the gradual decline in the quality of water in a well. This can be due to factors such as saline seep or by the movement of poorer quality water from a nearby water body or aquifer into the aquifer supplying the well. Either of these problems will eventually make the well water unsuitable for use.

Efficiency of a well is the theoretical drawdown observed in a well divided by the actual drawdown in the well. The theoretical drawdown can be calculated from the hydraulic properties of the aquifer and the actual drawdown can easily be measured at the well site. The term drawdown is actually the difference between the pumping water level in the well and the static water level in the well. Static water level is the depth from the measuring point at the top of the well casing to the water level in the well when not being pumped. The pumping water level is measured from the measuring point at the top of the well down to the water level when the well is being pumped. The difference between these two water levels is termed the drawdown of the well. For example, if the difference between the pumping level and the static level is 60 feet, then the drawdown of the well is 60 feet. If the theoretical drawdown of this well is 30 feet, then the efficiency of the well is 30/60 or fifty percent. The efficiency of a newly drilled well is 30 to 75 percent. After development, these wells are typically 60 to 90 percent efficient. The less efficient a well is, the greater the drawdown in the well for a given yield of water. This means that the water must be pumped a greater height to yield the same amount of water. To accurately measure the efficiency of a well requires a trained hydrologist or groundwater engineer who is experienced in this type of problem. The difference in cost between an efficient and an inefficient well may amount to several hundred dollars per year.

Well efficiency is an important factor, and design and construction of a well is an important consideration in overall well costs. It is possible to redevelop old wells that have become inefficient and in some cases to

reconstruct wells to significantly increase well efficiency. In many well systems, however, the basic construction design of the well would be difficult to change making it more economical to drill a new well to replace the inefficient well.

Well System Operating Program

Wells are very expensive and should have a carefully planned, systematic program to insure that they are kept in good health. A systematic program consists of the following:

1. Records: A complete record should be maintained on construction of the well, test drilling that preceded the well and test pumping data that preceded selection of pumps for the well. The pump equipment and well house specifications should be on file. Amount of water pumped, power, and maintenance costs should also be recorded.

2. Sanitation: A well should be examined to insure that the top of the well is properly sealed and that sources of pollution are avoided. The well water should be tested, both for coliform bacteria and for dissolved minerals. This testing should be periodic to see if the water meets applicable drinking water standards and to insure that the water is not producing bad odors or colors.

3. Maintenance: A periodic program is needed to check the pump, the drop pipe, and the motor. Typically, pumping machinery is pulled from the well at an interval of three to six years. It is important that the well does not pump dry or suck air. The well house should be kept dry and clean.

4. Efficiency: A periodic check of pump efficiency and well efficiency should be scheduled to check the well condition and to determine the pumping costs for each well in the system. Pumping schedules in the well system should be adjusted such that the most water is pumped from the well that produces water at the least cost.

The steps outlined above require some time from a water system operator and some understanding of how a well works in a water system. Considering the cost of well replacement and the cost of producing water from wells, it is important that operators "get to know their wells."

SECTION 2

DISTRIBUTION SYSTEMS

After collection and processing of a water supply, the distribution system must deliver it to the ultimate users. To be adequate, a distribution system must be capable of furnishing an ample supply of water of satisfactory sanitary and aesthetic quality whenever and wherever it is required in the service area. The system must maintain adequate pressures for normal residential, commercial, and industrial uses and for providing the supply necessary for fire protection. It is usually necessary to raise the water to a sufficient elevation to provide the pressures necessary to distribute it through the individual customer services and meters. In most systems, distribution storage is necessary to equalize and reduce the peak loads placed on the production and transmission elements of the system. Booster pumping is often required to serve more elevated areas or remote customers. The distribution system includes the pumps, distribution storage, pipe lines, control valves, and hydrants.

Water Usage and Losses

Rarely does a system produce or serve water at an average rate. The rate varies considerably over the year and during the day and differs in various sections of the country and in different types of communities. The delivery of water to the system is commonly expressed in millions of gallons per day (mgd) or gallons per capita per day (gpcd). The latter is obtained by dividing the amount of water delivered daily to the system by the population served.

The water processed in the production works does not all reach the ultimate users. Even in a fully metered system, there are uses and losses that cannot be fully accounted for, such as water discharged from hydrants for flushing streets and sewers, leakage and evaporation from reservoirs, and in particular, water used for fire fighting. A portion is lost in leakage and joints in pipe lines, from broken pipe, faulty valve and hydrant packing, and the like. Even customer meters cannot accurately record all water passing through them particularly at very low rates. The difference between the net plant output and the sum of metered or estimated flow through customer services is generally referred to as "unaccounted-for water." The losses and uses in such unaccounted-for water must be recognized in estimates of actual consumption.

Pressure Requirements

An adequate distribution system must be able not only to furnish the necessary flow of water to various points in the system, but also to maintain the pressures necessary to furnish each customer with sufficient pressure at the connection to satisfy normal requirements. Another reason for maintaining adequate pressure is to prevent the possibility for an occurrence of negative pressure. Negative pressure creates back-siphonage and contaminants can enter the water system.

A water system should be designed to maintain a minimum pressure of 20 lbs./inch^2 at ground level at all points in the distribution system under all

conditions of flow. When 20 psi pressure is maintained in the main, even when fire flow is being drawn from hydrants, the residential customer is assured of adequate pressure to furnish water for domestic services. The fire flow standards set by the National Board of Fire Underwriters (NBFU) also requires a minimum residual water pressure of 20 psi during flow. Residual pressure is defined as the pressure in the main system near where hydrant flows are taking place. Systems providing fire flow should have a minimum pipe size of six inches.

A pressure of 35 psi is a more desirable minimum for normal residential requirements. Normal pressures in a distribution system under average conditions of flow should range between 50 and 80 psi. Pressures in excess of 100 psi should preferably be avoided to minimize leakage, but sometimes they cannot be. When such high pressures are necessary, it is wise to have the individual customers provide pressure-reducing valves to limit the pressures to 100 psi or less.

As outlying areas of towns and cities are developed and water main extensions are made for service, it becomes necessary to assure the public of all the conveniences of potable water supplied at good pressures and in adequate quantities. Fire service must also be sufficient. For this reason, all plans for water system improvements must be submitted to the Water Quality Bureau of the Department of Health and Environmental Sciences for review and approval.

Centrifugal Pumps

Centrifugal pumps are pumps containing a rotating impeller mounted on a shaft turned by the power source. The rotating impeller increases the velocity of the water and discharges it into a surrounding casing shaped to slow down the flow of the water and convert the velocity to pressure.

Each impeller and matching casing is called a stage. The number of stages necessary for a particular installation will be determined by the pressure needed for the operation of the water system and the height the water must be raised from the surface of the water source.

When the pressure is more than can be practicably or economically furnished by a single stage, additional stages are used. A pump with more than one stage is called a multistage pump. In a multistage pump, water passes through each stage in succession, with an increase in pressure at each stage. Multistage pumps commonly used in individual water systems are of the turbine and submersible types.

1. A deep-well turbine pump is a combination of several stages of centrifugal impellers connected in series to a common shaft.

2. A submersible pump achieves the lifting of water from deep wells by means of a completely submerged motor coupled to the pumping unit. This arrangement eliminates the conventional line shaft of the vertical turbine pump with its necessary bearings, alignment, lubrication, friction loss, etc. The submersible pump unit has four advantages over other types of pumping units:

a. Crooked wells unsuitable for other types of pumps may be pumped.

b. Wells subject to flooding can be completely sealed by use of this pump.

c. A minimum amount of surface equipment is needed.

d. The operation is silent.

It also has some disadvantages:

a. Repair to motor or pump requires pulling it from the well.

b. The electrical equipment must be sealed tight to prevent entry of water vapor.

c. Sand damages the pumping unit.

The type and size of the pump selected for a particular installation should be determined on the basis of the following fundamental considerations:

1. Yield of the well or water source.
2. Daily needs and instantaneous demand of the users.
3. Size of pressure or storage tank.
4. Size and alignment of the well casing.
5. Total operating head pressure of the pump at normal delivery rates, including lift and all friction losses.
6. Availability of power.
7. Ease of maintenance and availability of replacement parts.
8. Initial cost and economy of operation.
9. Reliability of pumping equipment.

The pump must be sized to meet the needs of the particular water system.

Distribution Storage

The principal function of distribution storage is to make it possible to process the water at times when facilities would otherwise be idle and to distribute and store it in advance of its actual need at one or more locations in the service area closer to its ultimate users. The principal advantages of distribution storage are:

1. The demands on the sources of supply, the production works, and transmission and distribution mains are more nearly equalized; sizes and capacities of these elements need not be so great.

2. System flows and pressures are improved and stabilized better to serve the customers throughout the service area.

3. Reserve supplies are provided in the distribution system for contingencies such as fire fighting and power outages.

That portion of distribution storage related to normal operating uses serves to provide a supply at various points in the distribution system to help meet the peak rates and more nearly equalize the rates of flow and pressure. In effect, it decreases the necessary size of, and investment in, the facilities through which the water passes before reaching the point of storage.

The principal types of distribution storage facilities in common use are:

1. Lined or unlined earth embankment reservoirs - Earth embankment reservoirs were probably the first type of distribution storage in common use. They were generally installed on higher ground than the service area in order to provide water by gravity flow. The reservoirs were paved with stone riprap, brick, or concrete on the slopes and bottoms, and almost always open to the atmosphere.

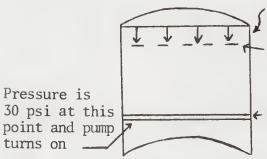
   The construction of open reservoirs is now prohibited by most State Health Departments since water stored in such structures is susceptible to pollution and deterioration. The cost of covering earth embankment reservoirs is exceedingly high and it is generally less expensive to replace the reservoir with other types of storage facilities.

2. Concrete ground-level reservoirs - This type of reservoir can be considered the replacement for the earth embankment reservoir. These are watertight reservoirs usually constructed below normal ground surface but placed above the ground water table. The top of the reservoir must not be less than two feet above the normal ground surface. The reservoir is designed with reasonably convenient access to the interior for cleaning and maintenance. The structure is usually placed at an elevation higher than the service area to provide gravity flow to the system.

3. Elevated storage provided by steel tanks - An elevated steel tank provides a convenient means of distribution storage. It can be located in the center of the service area to maintain sufficient pressure in the distribution system while providing an adequate supply of water to meet peak demands. As long as the tank has a solid watertight access cover which overlaps the framed opening and a screened, downward opening overflow pipe, the water storage is protected from outside contamination.

4. Pressure tanks - Many small water systems (trailer courts, subdivisions) contain a pressure tank. The tank stores a small quantity of water under pressure. Pressure is developed by forcing water into the tank until the air in the tank is compressed to a pre-set pressure.

When an outlet is opened, the pressure forces water out. As water leaves the tank, the pressure drops. When the pressure falls to a pre-set level, the pump starts and forces water into the tank. The air in the tank is compressed until it reaches a certain pressure and then the pump shuts off.


As the tank fills up, the air is compressed and therefore exerts greater pressure.
When the separator reaches this point, the pressure is 50 psi and pump shuts off.
Pressure is 30 psi at this point and pump turns on
Movable air-water separator

A pressure switch is used to start and stop a pump automatically at predetermined tank pressures. The switch has two adjustments: one to set the cut-in or "pump on" pressure, and the other to adjust the difference between the "on" and "off" pressure. Most switches are factory adjusted for specific pressures, but many can be readjusted within the limits of the switch rating.

The pressure tank volume needed for a water system depends on the well yield, pump capacity, maximum water requirements, and the operating pressure and pressure ranges selected. The storage capacity of a tank is usually small when compared to the daily water used. Tanks are customarily designed to accommodate only momentary peak demands because only ten to twenty percent of tank capacity is available. Most water systems should have a pressure tank with a usable storage capacity (volume, in gallons, between "on" and "off" pressure) of approximately two times the pump capacity in gallons per minute.

Pipe, Valves, and Hydrants

Pipe

Pipe must have sufficient strength to resist a variety of forces. Pipe is usually covered by a layer of dirt or gravel for protection from damage and freezing. If laid in a street it must be able to withstand the load of passing vehicles. The pipe must also be able to resist damage from impact. The ability to withstand forces such as these is a measure of the crushing strength of a pipe.

In addition to external pressures, pipe is subjected to internal pressures from water: delivery pressure, surges and water hammer. Water hammer is the tremendous force that is created by a sudden change in the water's velocity such as that caused by closing a valve too quickly or starting pumps too rapidly. Water hammer travels rapidly through the pipe and can cause extensive damage by rupturing pipe and tearing out valves.

Bursting strength refers to the ability of the pipe to withstand internal forces. When pipes are rated for either crushing or bursting strength, an extra margin is included as a safety factor.

Pressure ratings of pipe refer to the working pressure to be expected within a pipe. The pressure ratings take into account internal pressure and a safety factor. Normally pipe is carefully chosen to ensure that its pressure rating is adequate to handle the pressures in a system. For these reasons, personnel replacing a section of pipe should be careful that a new piece has a pressure rating equal to or greater than that of the replaced piece. Generally there are four classes of working pressure that are commonly encountered. They are 100, 150, 200 and 250 psi. When a pipe is subjected to pressures either external or internal that exceed its ratings, it may rupture or be crushed.

Other common types of breakage are shear and beam breakage. A shear break occurs when the earth shifts. Beam breakage, which resembles a shear break, may occur when a pipe is unevenly supported along its length. Much as a teeter-totter breaks at its fulcrum when the ends are overloaded, a pipe that passes over a narrow and unyielding support point, like a rock or wall, may break when it is loaded like a beam. Other types of beam breakage may occur.

The durability of the pipe refers to its ability to exist for a long time without deterioration. This is especially important to a water utility because pipelines are expected to provide service for many years. Frequent replacement of pipelines would mean higher rates for the consumer. Several factors are critical for a pipe to be considered durable. These factors can be assigned to the inner surface and the exterior surface of the pipe.

The inner surface of the pipe should not react with the water, should resist corrosion, and should have satisfactory flow characteristics. One of the factors generally affecting capacity is the friction of the water against the pipe. The amount of friction is dependent upon the roughness of the inner surface. The C factor of a pipe is a coefficient used in a pipe flow formula and refers to the pipe's interior roughness The smoother the interior surface the higher the C factor. New pipe used by water utilities usually has a C factor in the 100-150 range. A good durable pipe will maintain a smooth surface (high C factor).

The exterior surface of the pipe must be corrosion resistant. If the pipe is iron or steel, protection may be needed to avoid rusting. Coatings and linings are the most prevalent methods of providing corrosion control.

Installation features are taken into consideration when a particular pipe is chosen. Some of the installation features that are important are weight, jointing, available sizes, and ease of tapping the line. Weight is important because, in general, the heavier the pipe, the more expensive the installation. Jointing is important not only for ease of installation but also with regard to any possible flexibility or deflection. Size is critical because some types of pipe may not be available in the desired size. The ease of tapping may be important, depending on whether or not other lines (such as service lines) are to be attached to the pipe.

Standards that are generally recognized as desirable requirements for piping have been established by AWWA, ANSI (American National Standards Institute), NSF (National Sanitation Foundation) and ASTM (American Society for Testing and Materials). These guidelines have been established by experimentation and through actual experience in the field.

Valves

Valves are produced in many different designs. The four most common types encountered by a water operator are diaphragm, globe, rotary, and slide.

A diaphragm valve (Figure 2) has a flexible piece inside the body of the valve, which can be adjusted up or down by an attached stem. The piece can be made from rubber, leather, or some flexible material that is attached to the perimeter of the valve. When depressed, the piece serves to stop or regulate the flow of water.

Globe valves (Figure 3) have a flat or tapered disc of rubber or leather that is raised or lowered (as in a common home faucet) onto a seat. When the disc contacts the seat, the flow of water through the valve is stopped. Other globe valves are of a needle design. They have a cone-shaped piece protruding into the waterway to restrict or stop the flow. A needle valve is satisfactory for precise adjustments or small flows. Globe valves can be designed for straight, angle or y-pattern flows. They are sometimes controlled by a diaphragm that controls the valve's position using pressure differentials across the diaphragm, making them suitable for automatic control.

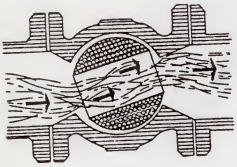
Rotary valves include ball, butterfly, cone and plug types (Figure 4, 5 and 6). Ball valves have a round sphere inside them. The sphere has a passageway which can be rotated so that water can flow through the valve, be restricted, or stopped. The sphere is positioned between resilient seat washers that prevent leakage. Cone valves are designed so that a cone-shaped element can be rotated within the valve body. The cone piece has an opening through it, which provides for full flow when the valve is completely open. The cone may also be turned to restrict or shut off the flow. Plug valves, similar to cone and ball valves, have a cylinder with a hole, which can be turned to open, restrict, or close the flow. Butterfly valves are designed so that an internal disc can be turned either to block or allow the flow of water. This disc is connected to a shaft that extends into or through the valve body. Rotary valves usually have a 90 degree rotation movement with a notch, arrow, or indicator to show valve positions.

Gate valves (Figure 7), sluice gates (Figure 8), and shear gates (Figure 9), are types of slide valves. A gate valve has a disc that rises from or drops into the flow and moves in a channel that keeps it aligned. Sluice gates are usually rectangular and are raised or lowered to control flows. The gate moves in a frame built into a dam, weir, bulkhead, or channel. Generally the design is such that the pressure of the water behind the gate serves to seal it. Shear gates are valves that have a plate covering the valve

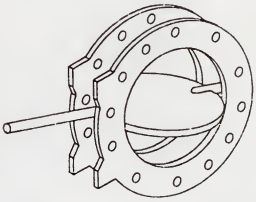
opening. The plate is rotated on a pin at one side of the seat and slides over the opening. It is moved by a rod that is attached opposite the pin. When the plate is closed, a wedge forces it against the end or seat of the valve.

DIAPHRAGM VALVE
Figure 2

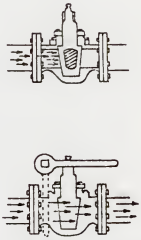
GLOBE VALVE - Figure 3



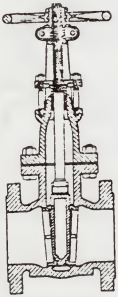
BALL VALVE - Figure 4



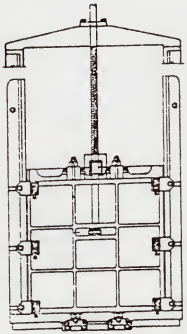
BUTTERFLY VALVE - Figure 5



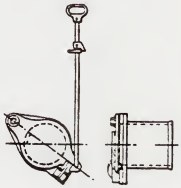
PLUG VALVE - Figure



GATE VALVE
Figure 7



SLUICE GATE - Figure 8



SHEAR GATE VALVE - Figure 9

Valve Applications

Valves have many uses in a water distribution system. Diaphragm, slide, rotary, and globe valves can be used to provide starting and stopping functions. Globe, diaphragm, and rotary valves are usually used to regulate flows: some slide valves can also be used for that purpose.

Pressure regulating valves reduce the water pressure by restricting the flow. Pressure on the downstream side of the valve regulates the amount of flow permitted through it. This type of valve is usually of the globe design with a spring-loaded diaphragm that sets the amount of the opening. As downstream pressure is exerted against the diaphragm, the spring is compressed, moving the valve element toward the seal, thereby limiting the flow. If the downstream pressure drops, the spring will open the valve element and provide more flow.

Air in water lines collects at peaks and at high spots. These pockets of air can increase the resistance to flow by 10-15 percent. An air-lock condition might stop the flow of water completely. Vacuum conditions can occur in pipelines during draining of the line, which can cause the collapse of some pipelines. To alleviate these problems air and vacuum relief valves use a float to operate. When the water level is low in the pipe or when enough air accumulates in the valve, the float drops and allows the entry or exit of the air. When the water level rises, the float closes the opening and provides a watertight seal. On some models a small quantity of water is permitted to escape; therefore adequate drainage should be provided. If the air and vacuum relief valves are installed in a vault, there should be adequate venting.

Properly designed air and vacuum-relief valves function in a way that prevents large volumes of air from blowing the float into a constant closed position. Air and vacuum-relief valves can be combined as one unit, which is normally preferred for its economy.

Blowoff and drain valves are usually placed at low spots in water lines. These on-off type valves are used to dewater lines for repairs or to blow off any sediment that accumulates at low points.

Sectionalizing valves are gate valves that are installed at various points in the water distribution grid. Normally two valves are placed at an intersection of pipelines to permit the isolation of areas under repair or areas of contamination. Adequate placement of sectionalizing valves prevents large areas of service from being without water during main repairs.

Back-flow prevention or cross-connection control can be obtained through the use of specific valve units. These units provide for normal flow, but when pressure levels drop or back-flow occurs, these valves close off the flow of water. Globe or swing designs are normally used for this purpose. A double check-valve arrangement is generally used in back-flow prevention. A check valve is a type of valve designed to permit flow in only one direction. When this type of arrangement is used, a means must exist for testing the effectiveness of the check valves. This is accomplished by installing petcocks between valves to check for reverse leakage.

A water utility may desire to maintain the water level in a reservoir at a certain elevation, which can be accomplished through the use of an altitude valve. This type of valve is generally operated by the water pressure or a float and is usually a globe valve.

There are many other valve applications in a water utility. The operator should attempt to learn the function of the valves in a system and learn to recognize their design characteristics.

Valve Operation

Valves can be operated either manually or by power operation. Manual operation of valves can be accomplished by the direct turning of the valve stem or be a geared arrangement to permit easier turning of the stem or large valves. The power operation of valves can include a motor or air piston to operate the stem.

When one operates valves, two types of problems can occur: cavitation and water hammer. Both of these problems can be costly to a water utility but can be avoided through proper operation and design.

Frequently in the operation of valves, conditions cause a partial vacuum or void to occur on the downstream side of a valve. These voids will fill with low-pressure vapors from the water. When these pockets implode or collapse they create a mechanical shock that causes pockets of metal to break away from the valve surface. A noisy or vibrating valve may be an indication that cavitation is occurring, which will eventually result in leaks and a valve that is unsuitable for service.

Water hammer is caused by closing valves too quickly. When water is suddenly stopped, shock waves are generated, which cause large pressure increases throughout the system. These shock waves travel quickly and can cause extensive damage. Water hammer during operation of valves can be prevented if the operator remembers to close valves and hydrants slowly.

Hydrants

Fire hydrants are primarily of two different designs: dry barrel and wet barrel. Dry barrels have their operating valve at the bottom, which makes it possible to remove all the water in the hydrant. This prevents any damage that could be caused by freezing. Wet-barrel types have their operating valve at the outlet. These hydrants can only be used in areas not subject to freezing.

A hydrant may have from one to four nozzles, the most common being equipped with two $2\frac{1}{2}$-inch hose nozzles and one $4\frac{1}{2}$-inch pumper nozzle. The size of hydrant refers to the size of the main valve opening which may vary from 4 to 6 inches in diameter. For two hose nozzles and one pumper nozzle, a hydrant should usually have at least a 5-inch valve opening. Hydrant barrels are made of cast iron and the moving parts are usually bronze. The barrel and operating mechanism should be designed so that, in the event of damage or breaking of the hydrant above or near ground level, the main valve will remain reasonably tight against leaking or flooding.

Fire hydrants are often used for purposes other than fighting fires. Pipelines are flushed with the use of hydrants. (This is often used to rapidly fill a small distribution system with chlorinated water for disinfection purposes.) Hydrants also provide water for water trucks and other construction equipment. Where this occurs, some type of metering arrangement should be provided.

Cross Connections

A cross connection is defined as any actual or potential connection between a potable water supply and a source of contamination or pollution. Backflow (the unwanted reverse flow of liquids in a piping system) allows contaminated water to enter the potable system.

Backflow is caused by back-siphonage or back-pressure, or a combination of both.

1. Back-siphonage is caused by negative pressure or a reduced pressure in the supply piping. It is caused by:

   a. Gravity: When the water supply is lost and a fixture that is elevated is opened allowing air into the system, water will, by gravity, reverse flow.

   b. Undersized piping: High velocity water traveling through undersized piping can cause an aspirator effect and draw water out of branch pipes causing a partial vacuum and a reverse flow.

   c. Vacuum: Pumping water from a water supply (example is a fire truck) causes a pressure drop or negative pressure in the system. A break in the main or excessive usage at a lower level in the system can also be a cause.

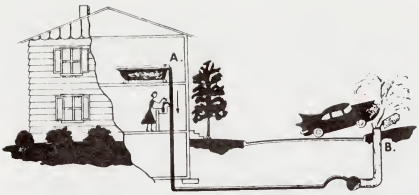
2. Back pressure backflow is the reversal of normal flow in a system due to an increase in the downstream pressure above that of the supply pressure.

The importance of cross connection control in the distribution system cannot be overemphasized. By far the greatest number of serious water-borne disease outbreaks have been caused by cross connections which allowed contaminated water to enter the system. Officials responsible for the inspection of plumbing installations should be alert to the possibilities of backflow and should require good plumbing practices that eliminate cross connections and backflow possibilities.

Each water distribution system should have a cross connection control program. Employees should be trained to detect improper and illegal connections.

Following are examples of common direct cross connection possibilities:

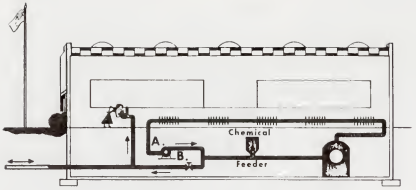
-A private well connected to the house plumbing. Although the well may be safe, it is not under the control of the water distribution



Backsiphonage

A. *Contact Point:* There is a submerged inlet in the second floor bathtub.

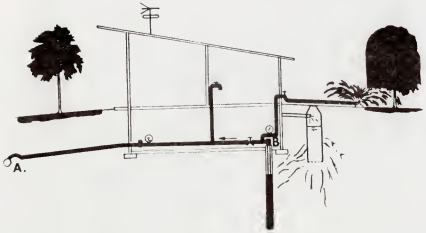
B. *Cause of Reversed Flow:* An automobile breaks a nearby fire hydrant causing a rush of water and a negative pressure in the service line to the house, sucking dirty water out of the bathtub.



Backflow

A. *Contact Point:* A direct connection from the city supply to the boiler exists as a safety measure and for filling the system. The boiler water system is chemically treated for scale prevention and corrosion control.

B. *Cause of Reversed Flow:* The boiler water recirculation pump discharge pressure or backpressure from the boiler exceeds the city water pressure and the chemically treated water is pumped into the domestic system through an open or leaky valve.



Backflow

A. *Contact Point:* Sewage seeping from a residential cesspool pollutes the private well which is used for lawn sprinkling. The domestic water system, which is served from a city main, is connected to the well supply by means of a valve. The purpose of the connection may be to prime the well supply for emergency domestic use.

B. *Cause of Reversed Flow:* During periods of low city water pressure, possibly when lawn sprinkling is at its peak, the well pump discharge pressure exceeds that of the city main and well water is pumped into the city supply through an open or leaky valve.

system and should not be directly tied to the same plumbing without proper backflow prevention measures.

-A fire water pump and system with a direct connection to the potable water. Industrial systems such as sawmills, refineries, etc., often have an auxiliary supply of fire water for emergencies. No connection should be allowed between the two systems.

-A pressured boiler with direct boiler feed water connections. Boilers are generally treated with chemicals which might be forced back into the system if the system pressure became less than the boiler pressure.

-Industrial processes with direct water connection.

The control of backflow and back-siphonage requires either the complete removal of the cross connection, or the installation of a proper cross-connection control device. Removal of the physical link is preferred because it eliminates the possibility of failure of a mechanical device. There are no cases where a cross connection cannot be removed or corrected. The only absolute means of eliminating the physical link is through the use of the vertical air gap. Air gaps should be used wherever possible, and where used, they should not be bypassed.

Where two or more piping systems are used for water in a building or industrial plant, extreme care should be taken to not interconnect the two systems. To help prevent the possibility of the two systems being interconnected, pipes should be identified by color coding and by legends based upon the American Standards Association "Scheme for Identification of Piping Systems."

Booster pumps are often required for high buildings. Frequently these pumps are connected directly to the city water main under which condition there is always the possibility of creating a negative pressure in the water main. A booster pump should be equipped with a low pressure switch to shut it down if the line pressure falls below a safe level.

Back-siphonage can occur only if there is a vacuum or negative pressure. If air is admitted to a piping system between a source of pollution and the vacuum source, back-siphonage will be prevented. This is the purpose of a vacuum breaker. It is not designed to provide protection against backflow resulting from back pressure and should not be installed where back pressure may occur. Because a vacuum may be created at numerous places in a piping system, a vacuum breaker must be located as near as possible to the fixture from which contamination is possible. The position of the vacuum breaker must be high enough above the fixture flood level rim so that flooding or submergence of the vacuum breaker cannot occur.

Installation of a vacuum breaker on the atmospheric side of the last control valve is always preferred and recommended because it then prevents any contamination from being siphoned into the water system. A vacuum breaker installed somewhere in the pressurized system does not completely protect the system and could allow back-siphonage into the water system.

In situations where it would be extremely difficult to provide a physical break between two systems and where back pressure can be expected, a reduced pressure zone backflow preventer (RPZ) can be used. This device consists of two pressure-reducing check valves with a pressure-regulated relief valve located between the two check valves.

For more information concerning cross connections and the methods of control, it is recommended that you obtain a copy of "Cross Connection Control Manual" available from the U.S. Environmental Protection Agency, Water Division, 1860 Lincoln Street, Denver, Colorado 80203, or from the State Water Quality Bureau.

It might be assumed that steps for detecting and eliminating cross connections would be elementary and obvious. Actually, cross connections may appear in many subtle forms and in unsuspected places. Reversal of pressure in the water may be freakish and unpredictable. The probability of contamination of drinking water through a cross connection occurring within a single plumbing system may seem remote, but, considering the multitude of similar systems, the probability is great.

Why do such cross connections exist?

First, plumbing is frequently installed by persons who are unaware of the inherent dangers of cross connections. Second, such connections are made as a simple matter of convenience without regard to the dangerous situation that might be created. And third, they are made with reliance on inadequate protection such as a single valve or other mechanical device.

To combat the dangers of cross connections and backflow connections, education in their recognition and prevention is needed. First, plumbing installers must know that hydraulic and pollutional factors may combine to produce a sanitary hazard if a cross connection is present. Second, they must realize that there are available reliable and simple standard backflow prevention devices and methods that may be substituted for the convenient but dangerous direct connection. And third, it should be made clear to all that the hazards resulting from direct connections greatly outweigh the convenience gained.

SECTION 3

BASIC HYDRAULICS

Hydraulics is the general study of the principles and laws governing the behavior of liquids, both at rest and in motion. There are two major divisions of hydraulics. Hydrostatics is the study of liquids at rest and hydrodynamics is the study of liquids in motion. Some of the fundamental principles of hydraulics should be understood by an operator of a distribution system. Perhaps the three most important concepts are quantity of flow, pressure head, and friction losses.

Quantity of Flow

Quantity of flow (Q) is the volume of flowing water in a pipe, conduit, flume or stream passing a given point in a specific unit of time. The flow may be partly unconfined, as in a flume or open stream, or under pressure, as in a pipe or conduit. Flow may be expressed in several different ways: cubic feet per second (cfs), cubic meters per second (m^3/sec), gallons per minute (gpm), millions of gallons per day (mgd), etc.

The basic flow equation is:

Quantity of water flowing = cross sectional area x average velocity

$$Q = A \times V = AV$$

The "A" in Q = AV stands for the cross sectional area of the flowing stream. For example, if the stream is in a rectangular flume, the cross sectional area is the width of the flume times the depth of the water. If the flow is in a pipe running full, the cross sectional area is found by a formula for the area of a circle. The "V" in Q = AV stands for the velocity of flow (speed at which the water is moving) and is usually expressed in feet per second (fps).

The flow equation simply states that the bigger the pipe (flume, conduit, ditch, etc.) through which water is flowing and the faster it is flowing, the more water that will be delivered per unit of time.

If area (A) is in square feet (ft^2) and velocity (V) is in feet per second ($\frac{ft}{sec}$ or fps), flow (Q) is expressed as cubic feet per second ($\frac{ft^3}{sec}$ or cfs).

$$Q = ft^2 \times \frac{ft}{sec} = \frac{ft^3}{sec} = cfs$$

Cubic feet per second may be converted into the more common term of gallons per minute (gpm).

$$1 \frac{ft^3}{sec} \times \frac{7.5 \text{ gallons}}{ft^3} \times \frac{60 \text{ seconds}}{\text{minute}} = 450 \frac{\text{gallons}}{\text{minute}} = 450 \text{ gpm}$$

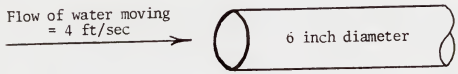
There are 7.5 gallons in a cubic foot.

← 7.5 gallons could be put into this cube

Therefore, one cubic foot per second (1 cfs) equals 450 gallons per minute (gpm).

$$1 \text{ cfs} = 450 \text{ gpm}$$

Example 1:



What is the flow rate Q?

Step 1: Find the cross sectional area of the pipe using one of three formulas:

$\text{Area} = 0.785\ D^2$ $\qquad \text{Area} = \pi\left(\frac{D^2}{4}\right)$ $\qquad \text{Area} = \pi r^2$

(where D = Diameter of the pipe, r = pipe radius (half of diameter), $\pi = 3.14$)

Change the diameter into feet: 6 inches = 0.5 feet

$$\text{Area} = 0.785 \times (.5 \text{ ft})^2 = 0.196 \text{ ft}^2$$

$$\text{or Area} = \frac{\pi \times (0.5 \text{ ft})^2}{4} = 0.196 \text{ ft}^2$$

$$\text{or Area} = \pi \times \left(\frac{0.5 \text{ ft}}{2}\right)^2 = 0.196 \text{ ft}^2$$

Step 2: $Q = 4 \frac{\text{ft}}{\text{sec}} \times 0.196 \text{ ft}^2$

$$= \frac{4 \text{ ft} \times 0.196 \text{ ft}^2}{1 \text{ sec}}$$

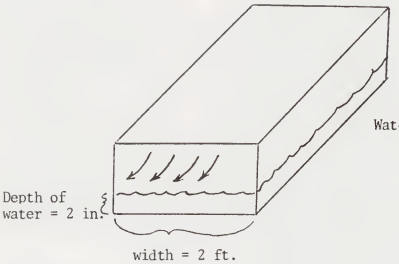
$$= 0.785 \frac{\text{ft}^3}{\text{sec}} = 0.785 \text{ cfs}$$

Step 3: Now convert cfs to gpm

$$0.785 \frac{ft^3}{sec} \times 7.5 \frac{gal}{ft^3} \times 60 \frac{sec}{min} = 353 \text{ gpm}$$

or $0.785 \text{ cfs} \times 450 \frac{gpm}{cfs} = 353 \text{ gpm}$

Example 2:



Step 1: Find the cross-sectional area of the water surface.

It is rectangular, therefore: A = width x depth
(Remember to change the height of the water into feet.)

$$2 \text{ in.} \times \frac{1 \text{ foot}}{12 \text{ in.}} = 0.17 \text{ feet}$$

Area = 0.17 feet x 2 feet = 0.34 ft^2

Step 2: Now compute Q

$$Q = 0.34 \text{ ft}^2 \times 2 \frac{\text{feet}}{\text{second}} = 0.68 \frac{ft^3}{sec} = 0.68 \text{ cfs}$$

Step 3: Convert to gpm

$$Q = 0.68 \text{ cfs} \times 450 \frac{gpm}{cfs} = 306 \text{ gpm}$$

At any pumping station it is necessary to measure the amount of water pumped in order to obtain and keep a record of the water produced. From this information, the operator can obtain useful data such as average daily water consumption and the peak rate of demand. A water meter for determining the output of each pumping staion is an essential element of any distribution system.

A handy method for determining flow when making field measurements is to use a bucket and a stopwatch. If you know how long it takes to fill a certain size of container, you have determined the flow.

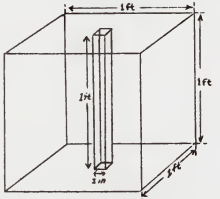
Example 3: A 5 gallon bucket is filled after 30 seconds.

$$Q = \frac{5 \text{ gallons}}{30 \text{ seconds}} = \frac{5 \text{ gallons}}{.5 \text{ minute}} = 10 \text{ gpm}$$

Pressure Head

Sometimes it is desirable to express the pressure in terms of the height of a column of fluid that will produce that pressure. The height of a column of liquid that produces the pressure is termed the pressure head. It can be expressed several ways. The most common are: head (in feet of water) and pressure (usually in pounds per square inch, psi).

The pressure at the bottom of a tank, column, etc. is dependent only on the height of the water and not on the volume of water in the container. For example, the pressure at the bottom of a 2 million gallon tank and of a 1/4 inch vertical pipe is the same if both are filled to 10 feet.



There are 62.4 lbs. of water in this cubic foot.

There are 144 - 1 in. x 1 in. x 1 ft. columns in this cubic foot.

If 144 square inch columns exert a pressure of 62.4 lbs; then 1 square inch column exerts a pressure of:

$$\frac{62.4 \text{ lbs}}{144 \text{ sq. in.}} = 0.433 \frac{\text{lbs}}{\text{sq. in.}} \quad \text{or psi}$$

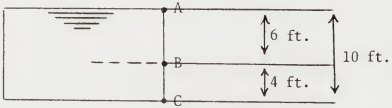
or a head of 1 foot of water = 0.433 psi

If one of the columns from above represents a pressure of 0.433 psi; then how long a column would represent a pressure of 1.0 psi?

$$\frac{1 \text{ psi}}{0.433 \frac{\text{psi}}{\text{ft}}} = 2.31 \text{ ft.}$$

A pressure of 1 psi = 2.31 ft.

Example 4:



1. What is the pressure at elevation A?
   Depth of water at point A = zero
   (There is no water above A.)
   Pressure Head = 0
   Pressure = 0 psi

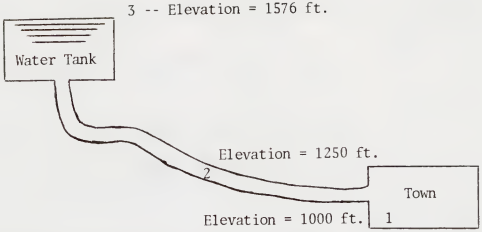
2. What is the pressure at elevation B?
   Depth of water over B = 6 ft.
   Pressure head = 6 ft.

   $6 \text{ ft.} \times 0.433 \frac{\text{psi}}{\text{ft.}} = 2.6 \text{ psi}$

3. What is the pressure at elevation C?
   Depth of water over C = 10 ft., therefore, Head = 10 ft.

   $10 \text{ ft.} \times 0.433 \frac{\text{psi}}{\text{ft.}} = 4.33 \text{ psi}$

Example 5:



1. What is the pressure at point 1?
   Elevation difference between points 1 and 3 - 1576 ft - 1000 ft = 576 ft.
   Therefore, pressure head is 576 ft.

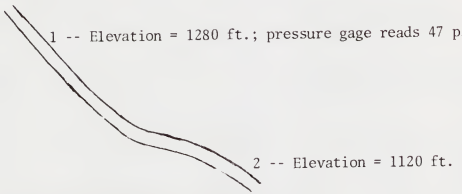
   $576 \text{ ft.} \times 0.433 \frac{\text{psi}}{\text{ft.}} = 249 \text{ psi}$

2. What is the pressure at point 2?
   Pressure head = 1576 ft - 1250 ft = 326 ft.

   - therefore -

   $\text{Pressure} = 326 \text{ ft.} \times 0.433 \frac{\text{psi}}{\text{ft.}} = 141 \text{ psi}$

Example 6:



What is the pressure head at point 2?
Pressure head at point 1 = $47 \text{ psi} \times 2.31 \frac{\text{ft}}{\text{psi}} = 108.6 \text{ ft.}$
Pressure head at point 2 = pressure head at point 1 plus elevation difference
= 108.6 ft. + (1280 - 1120)ft = 268.6
Pressure at point 2 = 268.6 ft x 0.433 psi = 116 psi

Now that you know what pressure head is and how pressure is determined, some simplifications can be made and some conclusions can be drawn.

1. Simply stated, water pressure differential can be determined if you know the elevation difference between two points in a distribution system. This difference in elevation is called the pressure head.

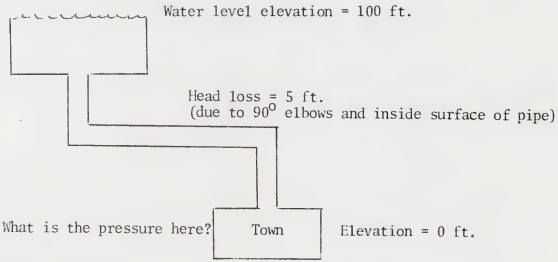
2. Knowing the pressure head between two points and the pressure at one of the points, the pressure at the other point can be determined.

3. Remember your conversions: 2.31 ft. of water = 1 psi
   1 ft. of water = 0.433 psi

Friction Loss

The concept of pressure head was somewhat simplified. Friction inside the pipe was not taken into account. The inside pipe walls, elbows, and joints, along with the effect of turbulent water flow, reduce the pressure head in a distribution system due to frictional forces. It should be remembered that some head loss occurs due to frictional forces. It should be taken into account when determining pressure head. Head loss is usually expressed in feet of water.

Example 7:


Water level elevation = 100 ft.
Head loss = 5 ft.
(due to 90° elbows and inside surface of pipe)
What is the pressure here?
Town
Elevation = 0 ft.

Pressure head = 100 ft.
But there is 5 ft. of head loss, so:
100 ft. - 5 ft. = 95 ft. of pressure head

$$\text{Pressure} = 95 \text{ ft.} \times 0.433 \frac{\text{psi}}{\text{ft.}} = 41.1 \text{ psi}$$

A water system operator should have some knowledge of the relationship between head loss and pipe diameter. Head loss in a pipe is inversely proportional to the diameter of the pipe. Simply stated, a larger diameter of pipe creates less head loss per foot of length than smaller diameter pipe.

Head loss in different types and sizes of pipe can be calculated from the Darcy-Weisback equation using experimental data obtained in the laboratory. A comparison of these data for different diameters of the same type of pipe points out the head loss-diameter relationship. Listed below are head loss data for Johns-Manville Permastran Pipe (pressures up to 350 psi).

Flow	Pipe Diameter	Head Loss (ft/100 ft of Pipe)
100 gpm	4	3.27
200 gpm	4	11.73
200 gpm	6	1.93
300 gpm	4	24.86
300 gpm	6	4.09
300 gpm	8	1.09
700 gpm	6	19.66
700 gpm	8	5.22
700 gpm	10	1.87

Replacing a certain diameter of pipe with two lines which are half the size of the previous diameter will not produce an identical flow situation.

Example 8:

Two 4-inch lines equivalent to the length of one 8-inch line do not produce the same amount of head loss. Observe the data for 4- and 8-inch diameter pipe with flows of 300 gpm. Head loss for two 1000-foot lengths of 4-inch pipe is 49.72 feet. Head loss for 2000 feet of 8-inch pipe is 2.18 feet. This is an appreciable difference!

SECTION 4

CHLORINATION

The disinfection of water may be defined as the destruction of pathogenic or disease-causing organisms. The term disinfection is not interchangeable with sterilization, which implies the destruction of all living organisms. Since public water supply systems are vulnerable to the transmission of water-borne diseases such as hepatitis, amoebic dysentery, typhoid fever, cholera, etc., disinfection is considered the most important single treatment step in the production of safe, potable water.

Because of economy and effectiveness, chlorination is the most commonly used process in potable water disinfection. Other processes are used such as chlorine dioxide, ozone, iodine, or ultraviolet light.

Chlorination of water is used for both disinfection and chemical oxidation. As a disinfectant, chlorine enters a bacterial cell through the cell walls and oxidizes the enzymes necessary for the life of the organism. When used for oxidizing purposes, chlorine reacts with organic compounds usually associated with taste, odor, and color.

It is impossible for laboratories to test for the large number of disease-producing organisms that may be found in a contaminated water supply system. What they do test for is coliform bacteria. Coliform bacteria, while not themselves disease producers, are often associated with pathogenic organisms and are a good index of the degree of bacteriological safety of a water. Coliform baceria occur normally in the intestines of humans and other warm-blooded animals and are discharged in great numbers in human and animal wastes. Coliform bacteria are always present in far greater numbers than disease-causing bacteria; therefore, their absence from water is an indication that the water is bacteriologically safe for human consumption. The presence of coliform bacteria, on the other hand, is an indication that disease-causing bacteria may also be present and that the water is unsafe to drink.

CHLORINE COMPOUNDS USED IN DISINFECTION

Chlorine Gas

Gaseous chlorine is greenish-yellow and visible in high concentration. It has a pungent, penetrating, irritating odor and is toxic. Chlorine gas is 2.5 times heavier than air and so will settle in low areas after a leak has occurred. Small leaks can be confirmed with the use of an ammonia-saturated cloth; chlorine reacts with ammonia to form dense white fumes of ammonia chloride. Chlorine gas in a moist atmosphere is highly corrosive. It is neither explosive nor flammable.

Chlorine is only slightly soluble in water and at temperatures below 49.2° F it will form a solid chrystalline hydrate, $Cl_2 \cdot 8\ H_2O$, sometimes referred to as "chlorine ice." This often can interfere with the normal operation of chlorinators and so it is recommended that chlorine rooms be heated to at least 55° F. Chlorine gas is packaged in a liquified form under pressure in steel cylinders. The vapor pressure in a cylinder is a function of temperature only and independent of the volume contained. Thus the pressure gauge will be of no use in determining the quantity of chlorine in the cylinder and a scale must be used for this purpose.

There are two types of gassing, or chlorine inhalation, that may occur:

1. The inhalation of dry gas is the most common occurrence. As soon as the gas is inhaled, the victim will sense a sudden stricture in the throat area — nature's way of signaling to prevent passage of the gas to the lungs. If chlorine gas is detected, leave the area immediately and seek medical attention!

2. The other type of gassing, and probably the more dangerous, is by chlorine fumes from an aqueous solution. This occurs in the case of a chlorine solution leak or exposure to a chlorine solution in a confined area, especially if the solution contains a concentration in excess of 750 ppm chlorine. Because the fumes are laden with moisture, they seem more tolerable to the respiratory tract and the victim will unwittingly inhale excessive amounts of chlorine. This results in a slow but significant production of pulmonary edema (liquid in lungs) that could cause death by "drowning." If chlorine fumes are detected, all work in the area should be conducted with a self-contained gas mask (NOISH-approved for chlorine gas). In a chlorine atmosphere all repair work should be conducted by two people, both with gas masks. One person fixes leaks and the other is a buddy for rescue.

Construction of the chlorine room can provide a certain amount of safety an operator needs. Some features of a good chlorine room are:

1. A power exhauster located at floor level, exhausting to the atmosphere.

2. A make-up air louvre at ceiling level and preferably opposite the power exhauster.

3. Safety brackets or chain devices to secure the chlorine tanks from tipping over.

4. The room light and power exhauster tied electrically to the same switch located outside the chlorine room.

5. A window in the door.

6. An approved gas mask should be located on the wall adjacent to the door and outside the chlorine room.

Calcium Hypochlorite $Ca(OCl)_2 \cdot 4\ H_2O$

Calcium hypochlorite is a white powder thay may be purchased in powder, granular, or tablet form under such trade names as HTH, Perchloron, or Pitchlor. It contains between 60 and 70 percent available chlorine on a weight basis. It is generally mixed with water to form a solution that is pumped into the system for disinfection or oxidation purposes. However, it also may be fed with a dry chemical feeder in a non-pressurized situation.

Calcium hypochlorite solutions are corrosive and appropriate precaution should be taken in its handling. The dry chemical can be explosive or flammable when mixed with certain organic material such as oil and this must be taken into consideration when storing the chemical.

Sodium Hypochlorite NaOCl

Sodium Hypochlorite is sold as a liquid solution containing 3 to 19 percent available chlorine on a weight basis. It is sold under a variety of trade names and it is most commonly seen as household bleach, such as Chlorox. Sodium hypochlorite is often used to disinfect small wells but its use is not widespread in large municipal systems.

Terminology

Chlorine Demand - quantity of chlorine required to react with chemicals and other substances in a water. It is usually expressed as a concentration (mg/l or ppm).

Chlorine Residual - quantity of chlorine remaining after a certain contact time or usually after the chlorine demand has been satisfied. It is expressed as a concentration.

Free Available Chlorine - or free chlorine concentration of hypochlorous acid and hypochlorite ions existing in a solution.

Chloramines - family of compounds that are formed from the reaction of chlorine and ammonia in water and are referred to as combined chlorine. Chloramines are much slower acting and much less effective than free chlorine in their disinfecting power. However, they maintain a residual for a much

longer time and will not evaporate from an open supply as readily as free chlorine.

Breakpoint Chlorination - the application of chlorine to water to produce a free chlorine residual.

Factors Affecting Chlorine Disinfection

1. Chlorine concentration: the higher the concentration, the more effective the disinfection and the faster the disinfection rate.

2. Type of chlorine residual: free chlorine is a much more effective disinfectant than combined chlorine.

3. Contact time between the organism and the chlorine: the longer the time, the more effective the disinfection.

4. Temperature of the water in which the contact is made: the higher the temperature, the more effective the disinfection.

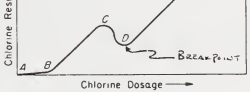
5. The pH of the water in which contact is made: the lower the pH, the more effective the disinfection.

6. Reducing Agent: any chemical or compounds that react with chlorine such as iron, nitrates, ammonia, manganese, hydrogen sulfide, etc. will decrease the effectiveness of disinfection.

Breakpoint Chlorination

The term breakpoint implies that the characteristic curve in the graph of chlorine residual vs. dosage produced. However, many waters will not demonstrate a breakpoint and term free residual chlorination is coming into wider usage. The implication is that sufficient chlorine has been added to produce a free chlorine residual regardless of whether a breakpoint was observed.

There are several distinct regions on the breakpoint curve (see diagram). On



the portion from A to B most of the chlorine reacts with reducing agents and very little residual is produced. Between B and C the chlorine is forming chloramines. At point C a free chlorine residual is obtained and additional chlorine will then begin to oxidize the chloramines. At point D the oxidation of the chloramines is essentially finished and any further chlorine added will remain as free available chlorine. This is the most effective disinfecting form.

Chlorine Residual Determination

At this time, the DPD (diethyl-p-phenylene diamine) titrimetric and colorimetric methods are the two most common tests and are the best for field use for determining chlorine residuals. The OTA (orthotolidine arsenite) method is no longer acceptable according to the Environmental Protection Agency (EPA).

The DPD colorimetric method is basically the same as the OTA method. Both tests rely upon color development after the addition of a chemical to a chlorinated water for the determination of a chlorine residual. In the DPD colorimetric method, the chlorine residual can be determined by comparing the color development with known color standards or the use of a spectrophotometer and a standard curve; a pinkish color will develop in the presence of chlorine.

The DPD titrimetric method is also based upon color development. The procedure involves the addition of DPD No. 1 powder or solution to cause color development and then followed with the addition of FAS (ferrous ammonium sulfate) solution for decolorization. The free chlorine residual is then determined by the amount of FAS solution required for decolorization. The total chlorine residual can be determined by this method with the use of potassium iodine and FAS solution. The addition of the potassium iodine acts catalytically to cause chloramines to react with the DPD reagent. The FAS solution then indicates the chlorine residual.

A proper chlorine dosage should be great enough to satisfy the chlorine demand and provide a minimum free chlorine residual of 0.2 to 0.5 mg/l everywhere in the distribution system after a chlorine contact time of 30 minutes.

Disinfection of Mains and Other Equipment

All new construction, and any pipe or equipment that has been opened for repairs, if it is to come into contact with the potable water, must be disinfected before being placed into service. Disinfection starts with good construction and repair practices. Pipe should be inspected while being installed to be sure no trash, such as rags, bird nests, rodents, soil or weeds are present. Sanitary conditions should be maintained at all times. Open ends of pipe should be closed off at the end of each day. At the finish

of the construction or repair work, the section of pipe should be thoroughly flushed and then chlorinated according to AWWA Standard C601-68, which states:

> "Sufficient chlorine concentration to provide a minimum of 50 mg/l chlorine should be added to the mains. Valves shall be manipulated to prevent the treatment dosage from flowing back into the line supplying the system. Chlorine application shall continue until the entire main is filled with the chlorine solution. The chlorinated water shall be retained in the main for at least 24 hours, during which time all valves and hydrants in the section being treated shall be operated in order to disinfect the appurtenances. At the end of the 24-hour period, the treated water shall contain no less than 25 mg/l chlorine throughout the length of the main."

Under some conditions when it is necessary to reduce the contact time to less than 24 hours, a stronger initial dose of chlorine solution should be used. A 100 mg/l dose with an eight-hour retention time may be acceptable if the residual chlorine concentration is no less than 25 mg/l at the end of the eight-hour period. In the case of emergency repairs when the line may only be out of service for a short while, the slug of chlorine for disinfection may be increased to 500 parts per million (ppm).

Disinfection by chlorination must be followed by thorough flushing until the flush water shows the same chlorine residual at the outlet as the inlet. Samples should then be taken for bateriological testing.

It is important that a sufficiently high dose of chlorine be injected to provide a uniform disinfection throughout the length of the pipe. The ideal condition is to provide a portable gas chlorinator or hypochlorinator to inject the strong chlorine water continuously as the flush water is withdrawn at the end of the line. When strong chlorine residuals are present in the withdrawn water, the line can be assured to be full of the disinfecting solution. Make certain that the system does not contain high spots or dead ends that may contain only trapped air (fire hydrants, for example).

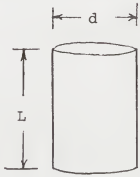
SECTION 5

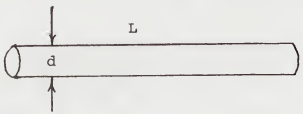
CHLORINE DOSAGE CALCULATIONS

An operator often needs to add chlorine to a water to obtain a desired dosage. The dosage is measured as parts per million (ppm) or milligrams per liter (mg/l). The terms are equivalent since one liter of water weighs one million milligrams. The expression of chlorine dosage as parts per million simply means that a ratio of the weight of chlorine to the weight of water is set up:

$$1 \text{ ppm} = \frac{1 \text{ lb Chlorine}}{1{,}000{,}000 \text{ lb water}} = \frac{1 \text{ ounce Cl}}{1{,}000{,}000 \text{ ounces water}} = \frac{1 \text{ gram Cl}}{1{,}000{,}000 \text{ gram } H_2O} \text{ etc.}$$

To determine the weight of water, the operator must be able to calculate volumes. Since one cubic foot of water holds about 7-1/2 gallons (actually 7.48), any known volume of water can be converted to a volume in gallons. Since one gallon weighs 8.34 pounds, any known volume can be converted to a weight. (A cubic foot of water weighs 62.4 lbs, which is 7.48 x 8.34.)





The formula for a cylinder (such as a pipe or round tank or drum) is:

$V = \pi r^2 L$ where $\pi = 3.14$

r = radius

L = length

radius is one-half the diameter

$r = \frac{1}{2}d$ or $d = 2r$

thus

$$V = \pi (\tfrac{1}{2}d)^2 L$$
$$= \pi (\tfrac{1}{2})^2 (d)^2 L = \pi (\tfrac{1}{4}) d^2 L$$
$$= \frac{\pi}{4} d^2 L$$

and since $\frac{\pi}{4} = \frac{3.14}{4} = 0.785$

$$V = 0.785\ d^2\ L$$

Units must be in $(\text{feet})^3$. Diameter of pipe is generally in inches, so it must be converted to feet. Dividing inches by 12 gives feet:

6" = how many feet?

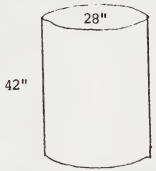
$$\frac{6 \text{ in.}}{12 \text{ inches/ft}} = \frac{6 \text{ in.}}{12 \text{ in/ft}} = \frac{1}{2} \text{ ft} = 0.5 \text{ ft}$$

Similarly

8 in. = 0.67 ft
12 in. = 1.0 ft

Example:

What is the volume of a barrel 42" high and 28" in diameter? And how much would the water in it weigh if full?



$V = 0.785\ d^2\ L$

$d = 28" = \frac{28}{12}$ ft $= 2.33$ ft

$L = 42" = \frac{48}{12}$ ft $= 3.50$ ft

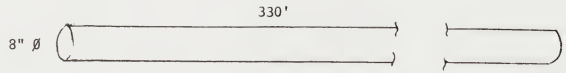
Volume: $V = (0.785)\ (2.33)^2\ (3.50) = 14.92\ f^3$ (answer)

Weight: 1 cubic ft weighs 62.4 lbs

$14.92\ f^3$ weighs 931 lbs (answer)

$$(14.92\ f^3 \times 62.4\ \frac{\text{lbs}}{f^3} = 930.75 \text{ lbs})$$

Example:



What quantity of water is required to fill a length of 8" pipe that is 330 feet long?

Quantity is usually volume

$V = 0.785\ d^2\ L$ $\qquad d = 8 \text{ inches} = \frac{8}{12} \text{ ft} = 0.67 \text{ f}$

$d^2 = 0.44\ f^2$

$V = (0.785)\ (0.44)\ f^2\ (330)\ f = 115\ f^3$ (answer)

or in gallons: $115\ f^3 \times 7.48\ gal/f^3 = 861$ gallons (answer)

* * * * * * * * *

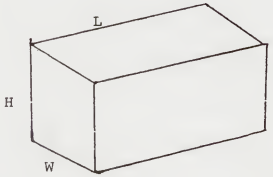
The volume formula for a rectangular tank is much easier:

$$V = L \times W \times H$$

Where L = length

W = width

H = height



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Now think about dosage. . . . . .

Suppose 8 lbs of chlorine gas is used to dose 887,000 gallons of water. The ratio must first be expressed in identical units such as pounds/pounds. We have pounds/gallons. . . .

887,000 gallons x 8.34 lbs/gal = 7,397,580 lbs or 7,400,000 lbs

$$\text{Dosage} = \frac{8 \text{ lbs}}{7{,}400{,}000 \text{ lbs}} = \frac{8 \text{ lbs}}{7.4 \text{ million lbs}} = 1.08 \frac{\text{parts}}{\text{million parts}} \text{ or } 1.08 \text{ ppm}$$

A dosage formula has been developed to be used for such problems:

pounds = mg/l x MG x 8.34

- Pounds refers to pounds of chlorine. If it is HTH (which is 65% available chlorine), this number must be divided by 0.65 to obtain lbs of HTH. For chlorine gas, no adjustment is necessary.
- mg/l is the dosage (remember, it is equivalent to ppm).
- MG refers to million gallons. If there are 3,000,000 gallons, then it is used as 3 MG in this formula. Simply divide the quantity of water by 1,000,000.

Try this:

A 10" main, 720 feet long, needs a dose of 65% HTH at 50 mg/l

1. What is the volume in f^3?
2. How many gallons of water?
3. What is the weight of the water?
4. Use the dosage formula to calculate lbs of chlorine needed.
5. Convert pounds of chlorine to pounds of HTH.

Solutions:

1. Volume?

$V = 0.785\ d^2\ L$ $\qquad D = 10" = \frac{10}{12}\ ft = 0.83\ ft$

$d^2 = 0.69\ f^2$

$V = (0.785)\ (0.69)\ f^2\ (720)\ f = 392.5\ f^3$ (answer)

2. Gallons?

$1\ f^3 = 7.48$ gallons

therefore: $392.5\ f^3 \times \frac{7.48\ gal}{f^3} = 2935.9$ gal (answer)

3. Weight?

$1\ f^3$ weighs 62.4 lbs - therefore:

$$392.5\ f^3 \times \frac{62.4\ lbs}{f^3} = 24492\ lbs \quad \text{(answer)}$$

4. Dose?

Pounds = mg/l x MG x 8.34

mg/l = 50

$MG = \frac{2935.9\ gals}{1{,}000{,}000}$

$Pounds = (50)\ \frac{2935.9}{1{,}000{,}000}\ (8.34)$

= 1.22 lbs chlorine needed (answer)

5. Convert lbs chlorine to lbs HTH?

HTH is only 65% chlorine, so $\frac{1 \text{ lb HTH}}{0.65 \text{ lbs chlorine}}$

1.22 lbs chlorine x $\frac{1 \text{ lb HTH}}{0.65 \text{ lbs chlorine}}$ = 1.88 lbs HTH (answer)

* * * * * * * * * * *

The training officers of the Water Quality Bureau can supply further example problems if you desire.

SECTION 6

WELL CONSTRUCTION

The well operator should have an understanding of the following terminology:

Static Water Level - this is the distance from the ground surface to the water level in the well when no pumping is occurring.

Dynamic Water Level - or pumping level, is the distance from the ground surface to the water level in the well when the pump is activated.

Drawdown - is the difference between the static and dynamic water levels. This is also a measure of the head causing the water in the aquifer to flow toward the well.

Residual Drawdown - is measured during the recovery period after pumping and is the difference between the static water level and the water level seen in the well.

Well Yield - is the quantity of water pumped per unit time; usually gallons per minute (gpm).

Specific Capacity - is a measure of yield per unit of drawdown and is expressed in gpm/ft. For example, if a pumping rate of 320 gallons per minute causes a drawdown of 16 ft, the specific capacity is $\frac{320 \text{ gpm}}{16 \text{ ft.}}$ or 20 gpm/ft.

Most well operators do not have the opportunity to observe or participate in the construction of the wells they operate. However, familiarity with well construction techniques can be helpful in better understanding the principles of well operation. The two most obvious construction design parameters are diameter and depth. In determining optimum diameter, there are two considerations:

1) The casing must be large enough to accommodate the pump.

2. The diameter of the intake portion must be sufficient to ensure good hydraulic efficiency.

Depth is generally to the bottom of the aquifer, as this will give both a greater yield and a higher specific capacity. Doubling the diameter of the

intake portion of the well will only increase the yield by 10-15 percent. However, doubling its length will approach a doubling of the yield.

In designing the screened portion of the well, one must determine the optimum slot size, diameter, and material. Slot size is a function of the sand and gravel gradation found adjacent to the borehole. The screen diameter is chosen such that the entrance velocity of the water is less than 0.1 ft/sec. This assures low friction losses and also minimizes incrustation and corrosion. Design considerations governing the screen material are the water's mineral content (whether corrosive or incrusting in nature), any history of bacterial slimes, and any particular screen strength requirements.

Reference is often made to gravel-pack well construction. The zone surrounding the well screen is made more permeable by removing the natural formation material and installing a coarser, artificially graded mixture of sand and/or gravel. There are several situations in which gravel pack is recommended:

1. Aquifer of fine, uniform sand.

2. Aquifer is loosely cemented sandstone that may break up and clog the screen.

3. Very thick artesian aquifer where a screen with a diameter much smaller than the borehole would be used and the annular space filled with gravel.

4. Extensively laminated aquifers where it would be difficult to match the correct screen slot size with the corresponding gradations of formation material in the aquifer.

Generally, gravel pack construction is more expensive, with the additional cost attributable to the need for a larger hole (in some cases) and the purchase of specially graded gravel.

There is a construction technique identical to gravel pack with the exception that the fill material is not specially gradated. The material is then referred to as formation stabilizer. Its purpose is to prevent silt and clay from caving or slumping during development.

Sanitary protection of a well supply should be provided. It is important that polluted surface or subsurface drainage is unable to travel down the borehole and enter the potable aquifer. This is usually accomplished by capping the casing at the surface and sealing the upper portion by grouting. Some means of protection from flooding should be provided.

There are numerous ways to drill a well, but the general procedures in well construction are as follows:

1. Drill bore hole

2. Install casing

3. Install screen (and gravel pack, if used)

4. Seal by grouting

5. Development

Cable Tool Percussive Method

This method utilizes a string of drilling tools which are suspended by a cable and dropped to break up the formation. Fragments are suspended by a slurry of water and are periodically pumped or bailed from the borehole. In soft or unconsolidated materials it may be necessary to drive the casing simultaneously to prevent caving in.

Hydraulic Rotary Drilling

In this method, the borehole is cut by a rotating bit and the cuttings are removed by the continuous circulation of drilling fluid (generally, a specially prepared mud). Air rotary drilling is similar and uses compressed air as the drilling fluid.

Jet Drilling

This method uses a chisel-shaped bit with high pressure nozzles on its sides for loosening formation material and cleaning the bit. The water from the nozzles also serves to carry the cuttings in suspension to the surface.

Rotary Bucket Drilling

Some boreholes are cut with auger-type bits. A rotary bucket is a cylindrical bucket with auger cutting blades on its bottom.

Driven Wells

This method is simply driving a well point, which is a length of well screen with a steel point on its lower end, into the aquifer by hand or with a driving tool. Usually, the depth is less than fifty feet.

The most common procedure for installing a screen is by inserting the casing to the bottom of the borehole. The screen is then lowered in place and the casing is pulled back up to its proper height. A packing gland at the top of the screen is then flared to get a snug fit. There are other methods of screen installation that rely on excavation of the bottom of the borehole to allow the screen to sink to its proper level.

Well development refers to the processes that remove the finer materials from an aquifer to effectively open the passages in the formation to allow for the freer flow of water. Development corrects any damage to or clogging of an aquifer during drilling. It increases the permeability and stabilizes the formation near the screen. There are various methods of development but basically the fine sand is alternately loosened by high pressure surging and then removed by pumping.

Problems:

1. The static level of a well is measured at 38 feet below the surface. When pumping the level is lowered to 54 feet. The pressure gauge reads 86 psi and the flowmeter indicates 176 gpm. What is the specific capacity?

2. A well screen is pulled and found to be badly corroded and incrusted over its entire twelve foot length. The original drill log shows the aquifer to be almost 50 feet thick and the driller recommends installing at least 24 feet of screen on the replacement. What possible effects on performance could be expected?

Answers:

1. Drawdown = 54-38 = 16 feet

   Specific capacity = $\frac{176 \text{ gpm}}{16 \text{ ft.}}$ = 11 gpm/ft.

   Pressure is irrelevant

2. The yield could be expected to increase. Specific capacity would increase. No prediction of the effect on incrustation or corrosion can be made.

SECTION 7

WELL MAINTENANCE

Proper maintenance will improve well performance and prolong well life. The most important aspect of well maintenance is simply good record-keeping. By carefully monitoring well performance, an operator can see if a problem is developing and often can determine what steps are appropriate to remedy that problem. The operator should record daily pumpage, static and dynamic water level (hence, drawdown), pumping rate and corresponding discharge pressure, monthly power consumption, and any water quality analyses performed. A flowmeter, drawdown gauge and pressure gauges are invaluable tools for proper well operation.

The most obvious aspect of a well's performance is its yield. There are a number of causes for a decrease in yield such as:

- pump wear reducing pump capacity
- increase in dynamic load in the system
- drop in water table
- operation of a nearby well in the same aquifer
- clogging of the well screen
- clogging of the water-bearing formation near the bore.

The latter two are the most common problems and generally result from incrustation. Incrustation is the deposition or accumulation of extraneous material on the screen or in the water-bearing sand. It can be in several different forms, depending on its source:

- hard, brittle, cement-like
- soft, paste-like
- gelatinous

The most frequent cause for incrustation will be calcium and magnesium carbonates or sulfates. Other causes can be iron and manganese hydroxides, iron bacteria slime, and loose soil materials.

Incrustation is not corrosion. Corrosion actually eats the metal of the screen and casing, whereas incrustation deposits material. However, the products of corrosion can cause incrustation and the processes can occur simultaneously.

The process of incrustation cannot be prevented but the following would help to delay it to some extent:

- assure proper entrance velocity through screen (design)
- use multiple smaller wells to reduce drawdown (design)
- reduce pumping rate and pump for longer hours (design/ operation)
- a periodic cleaning program (operation)

Unfortunately, in most small municipal systems, cleaning is usually neglected until the problem is serious and then it may even be too late to be totally effective.

Cleaning is generally accomplished by acid treatment as it is effective on both the calcium/magnesium carbonates and the iron/manganese hydroxides. Hydrochloric acid containing an inhibitor (to minimize its corrosiveness on the metal casing) is usually used. Sulfamic acid (do not confuse with sulfuric) is also popular because it is effective on incrustation and is much less corrosive to metal than hydrochloric acid. If the incrustation source is bacterial slime growth, such as iron bacteria, then chlorine treatment is employed. Generally, it is dosed at a rate of 100-200 ppm. Polyphosphates, similar to household detergents, are also used in water well cleaning.

If corrosion is a major problem, then consideration should be given to use of corrosion-resistant well screens and casing materials.

SECTION 8

PUMPS

There are several ways in which types of pumps may be categorized. A broad classification scheme could be constant displacement versus variable displacement, where a constant displacement pump delivers virtually the same quantity of water regardless of head conditions encountered. A variable displacement pump would deliver water in a quantity that varies inversely with the head against which it is operating. The most important pump in this class is the centrifugal pump, which is almost universally used in the waterworks industry.

The constant or positive displacement pumps can be separated into two groups:

1. piston or plunger pumps
2. rotary pumps

Piston pumps are simply a piston in a cylinder fitted with check valves for controlling the flow of the water. Large piston pumps were once common for high-lift distribution pumps and are still used in many parts of the world. A major drawback is water hammer created by the oscillating action.

Rotary pumps utilize gears or vanes in a housing to push positive volumes of water. Screw pumps are a variation of rotary pumps. Many of the liquid chemical feed pumps in the waterworks industry are of the positive displacement type.

Variable displacement pumps would include centrifugal pumps, jet pump, and air lift pumps. As the head increases, the flow decreases. Air lift pumps do not actually "pump", but raise liquids. Compressed air is pumped into a column of liquid, reducing its specific gravity and thus raising it within the column. Air-lift pumps are sometimes used in well development.

Jet pumps utilize a centrifugal pump and a nozzle and venturi tube to create a partial vacuum to pump water. A portion of the water is recycled to the nozzle and this makes jet pumps inherently inefficient. However, they are useful in small diameter domestic wells and have the advantage of all moving parts being on the ground surface.

Centrifugal pumps consist of a rotating impeller housed in a stationary casing. The impeller draws water into its center and the casing guides the water to the outlet. The high velocity is converted to pressure head consistant with the the basic hydraulics formula $h = v^2/2g$. (h = head; v = velocity; g = gravity). A larger inlet and impeller will pump a greater volume of water. Impellers may be classified as open, semi-open or closed. Centrifugal pumps may have single or double inlets. Multiple impellers are

referred to as stages and pumps can have as many as twenty or more stages. Volume capacity and efficiency remain constant but head and horsepower increase as a function of the number of stages in a multi-stage pump. Centrifugal pumps can be classified in several ways. One common way is by the type of pumping action which occurs:

1) radial flow: by centrifugal force

2) axial flow: by lifting action of impeller vanes

3) mixed flow: by combination of above.

Positive displacement pumps can move all fluids, even air, so priming is generally not a problem. However, centrifugal pumps require positive suction head to start. This is accomplished by any of the following means:

1. use a foot valve to contain water in the housing

2. incorporate a method for venting entrained air

3. have an auxiliary pump or water supply to fill pump and suction line

4. build in a self-priming mechanism.

In municipal wells, there are two principal methods of pumping; either suction lift or positive submergence. A perfect vacuum is equivalent to about 34 feet of water. It is impossible to raise a column of water 34 feet in height by suction. As the pressure drops, the liquid becomes a gas. In practice a suction lift of more than 25 feet is not recommended.

A submersible pump is a centrifugal pump close-coupled to an electric motor capable of operating while totally submerged under water. Its utility for water well service is obvious. An alternative would be a vertical turbine pump which is an above-ground power unit complete with a long drive shaft and bearing assemblies connected to the submerged impellers.

Cavitation is a serious problem in some pumping situations. When the pressure is reduced to the fluid's vapor pressure, gas bubbles form. When the fluid containing the bubbles moves to a region of higher pressure, the bubbles collapse violently and cause pitting and vibration in pumps and piping. Cavitation has a sound similar to that of gravel being pumped. The following are possible solutions to cavitation problems:

1. increase suction line pressure

2. reduce impeller speed

3. use a booster pump in-line

4. change impeller or pump.

A pneumatic ejector pump is simply a pressure vessel that is allowed to fill by gravity. At a predetermined level a charge of high-pressure air is introduced to force the slug of water out of the chamber and into the force main.

A diaphragm pump consists of an elastomeric diaphragm driven by a reciprocating mechanism. The most common example of this would be a fuel pump on an automobile.

The operator should have a working knowledge of common pump terminology:

Capacity - volume of water per unit of time (gpm)

Head - refers to the elevation of a free water surface elevation above a given reference point (feet)

Suction head (h_s) - is the difference between the suction liquid level and the centerline of the pump impeller. This number is treated as positive or negative, depending of whether the liquid level is above or below the pump.

Static discharge head (h_d) - is the difference between the liquid level of the discharge and the centerline of the pump impeller.

Static head (h_{stat}) - is the difference between the static discharge head and the suction head ($h_d - h_s$).

Friction head (h_f) - is the energy losses due to friction when the water is flowing. The quantity is converted to an equivalent additional quantity of head.

Minor head losses (h_m) - is the friction head losses through valves and fittings and bends.

Velocity head (h_v) - is the energy contained in the liquid due to the fact that it is in motion.

$$h_v = \frac{v^2}{2g}$$

Total Dynamic Head (TDH) - is the head against which the pump must work when pumping.

$$TDH = h_d - h_s + h_f + h_m$$

$$= h_{stat} + h_f + h_m$$

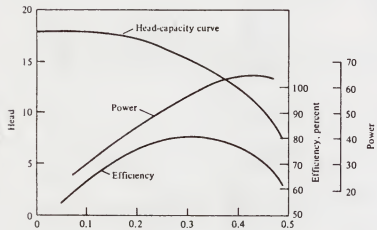
Pump manufacturers provide performance curves for each pump they produce. The basics of a pump curve diagram are:

1) head-capacity or flow rate as related to TDH

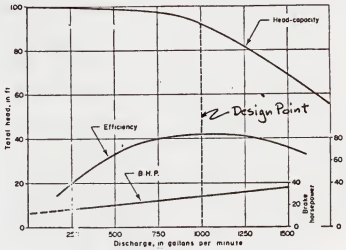
2) power required as a function of flow rate

3) efficiency as related to flow rate

Often the manufacturer's graphs are very confusing to read as many pumps can be operated at variable speeds or be fitted with a variety of impellers both of which alter the characteristics and thus, the curves. The design application of a particular pump is the point where the efficiency curve is highest.



Example 1



Example 2

Another graph that is a useful tool is the system-head curve. This is a plot of the total dynamic head versus flowrate for a variety of actual conditions encountered. Superimposing the pump head-capacity curve on the system-head graph will give the pump operating point at their intersection. This is especially useful when replacing a pump as it enables one to correctly choose the replacement such that its efficiency is maximized.

SECTION 9

VALVE AND HYDRANT MAINTENANCE

Gate valves and fire hydrants may seldom be used but they are very important and should be operable when needed. An organized program of inspection and maintenance is essential to help avoid serious problems that could arise.

Gate Valve Maintenance

Valves larger than 12" in diameter should be operated annually and smaller valves should be inspected at least once every three years. On smaller systems it is possible, and recommended, that all valves be inspected annually. Valve boxes located in streets should be checked periodically to see that they are not damaged, filled with debris, or paved over.

Valves are provided principally to isolate sections of a distribution system for emergency or short-term maintenance. Therefore most distribution valves suffer more from lack of use rather than wear.

It is a good idea to keep records on all gate valves and it should include location, type, size, make, installation date and major maintenance performed.

Important aspects of the inspection include:

1. Verify accuracy of location measurements;
2. Check valve box and cover for damage and note any debris in box;
3. Note whether the box should be raised or lowered;
4. The valve should be operated fully, in both directions. The number of turns to closure should be noted, as well as whether it is a left-hand or right-hand valve;
5. Any valves that are required to be left closed should be noted;
6. Badly corroded valves should be operated several times and flow should be induced by opening a hydrant to flush the valve seat;
7. The condition of the valve packing, stem, nut, and gearing should be noted.

From the results of the inspection program, a maintenance schedule may be worked out. Important aspects of the maintenance program should include:

1. Raise or lower gate valve boxes to grade;
2. Correct all erroneous or vague measurements. Markers or monuments may have to be set;
3. Replace damaged boxes and covers, remove debris;
4. Repair any packing leaks, replace inoperable valves.

There are few other procedures that the water utility can follow that will be of assistance in the gate valve maintenance program. A standard policy should be adopted on the type, and even the make, of gate valves used in the distribution system. A standard location policy should be set. Proper installation procedures are obviously important. Extra valves and important components, such as stems, should be kept in stock. Crews should also report the condition of valves after an emergency or scheduled shut-off has occurred. Inspections should be made after any construction or utility company work has been completed in an area.

Hydrant Maintenance

Fire hydrants, like valves, are installed essentially for emergency use and their operability should be considered critical. Because of their exposure, they are especially vulnerable to damage and vandalism. Hydrants should be checked and operated twice a year, in the fall and in the spring. This also serves to help flush the distribution system. The fall inspection is especially important because trapped water is prone to freezing in winter. During cold weather hydrants should be checked after each use.

Visual inspection should include:

1. Loose or missing caps, missing or broken chains;
2. Damaged nuts, cracked barrels;
3. Need for painting;
4. Clearance of nozzles above ground, interference from poles, posts, or other objects.

The operational checks should include:

1. Check for leakage with a listening device;
2. Flush by opening completely and then close down and check for complete drainage;
3. Check and lubricate nozzle threads;
4. Replace lost or damaged gaskets;
5. Lubricate the operating nut;
6. Repair or replace worn or damaged parts;
7. If the hydrant is gated, check its gate's condition and make sure it is in the "on" position.

Next a maintenance program can be initiated to correct any problems detected by the inspection. Those hydrants that suffer from improper drainage should be pumped to prevent their freezing.

The poor drainage can be caused by:

1. A plugged waste opening (drain holes);

2. A drainage system that has failed;
3. High groundwater table.

To remedy the plugged waste opening it is necessary to remove the inside assembly of the hydrant and clean out the opening. Where the drainage system has failed it is necessary to excavate the hydrant and replace the material around its bottom with crushed stone or gravel. This stone-filled drainage pocket should extend several inches above the drain holes and be at least twice the volume of the hydrant barrel. A drainbox made of creosoted planks is a good substitute for the gravel drainfield. In the event of a high water table, the drainholes must be plugged and the hydrant barrel pumped after each use. These hydrants should be noted and marked.

A leaking hydrant is repaired by removing its inside assembly and replacing or repairing the main valve and valve seat.

There are several considerations that management should implement to aid in a successful hydrant program. A standard hydrant should be chosen and a sufficient inventory of spare parts and extras should be maintained. Hydrants should be gated so that maintenance and repairs can be performed without a loss of service. Good records should be kept. A training program should be instituted for the local fire department covering the proper operation of fire hydrants. Often the fire department is willing to help with the inspection program and painting program. The painting of hydrants is a good public relations tool as they are the most conspicuous element (possibly except for standpipes) of a water system. Hydrants should be kept cleared of snow in the winter and if this is not always possible, their location should be marked with posts or flags.

SECTION 10

SUMMARY OF DRINKING WATER REGULATIONS

Suppliers of water have important responsibilities under the Safe Drinking Water Act. Therefore, public officials and private water system owners and operators must have a good working knowledge of the law and regulations in order to see that their system meets the requirements. Essentially you should be very familiar with the six following areas:

1. Definition of a public water system
2. Maximum contaminant levels
3. Sampling frequencies
4. Chlorination requirements
5. Reporting and record keeping
6. Public notificaiton

Definition of Public Water Supply

A "Public Water Supply" or "Public Water System" is a system for the delivery to the public of piped water for human consumption, if such a system serves at least 10 service connections or regularly serves at least 25 persons daily at least 60 days out of the calendar year. There are two basic types of public water systems.

1. A "community water system" is any public water system which serves at least ten service connections used by year-round residents or regularly serves at least 25 year-round residents. Examples of community systems are cities, towns, subdivisions, and trailer courts.

2. A "non-community water system" is defined as any public water system which is not a community water system. A non-community system serves a transient population; the same people do not drink the water every day. Examples of non-community supplies are bars, campgrounds, restaurants, etc.

Maximum Contaminant Levels (MCL's) and Sampling Frequency

An MCL is the highest concentration of a particular contaminant that is allowed in drinking water. An MCL is usually expressed in milligrams per liter (mg/l), which is the same as parts per million (ppm). There are currently MCLs for five categories of contaminants: bacteriological, inorganic, turbidity, organic, and radiological. Except for those relating to nitrate, bacteriological contaminants, and turbidity, the MCLs are designed to prevent health effects caused by drinking the same water over a long period of time.

Nitrate, bacteria, and turbidity, on the other hand, can be related to rapid onset of health problems. Because of this, non-community as well as community supplies are required to meet these three MCLs.

The operator of a small public water system should be very familiar with the bacteriological sampling procedure (on next page), sampling frequency, and the coliform bacteria MCL. A community water supply serving 25 to 1000 people must submit one sample per month for bacteriological analysis. A non-community water supply is required to submit one sample per quarter for bacteriological analysis. A community water system serving 25 to 500 persons, with written permission from the Department, may reduce the sampling frequency as follows:

25 to 100 people	1 sample per quarter
101 to 500 people	2 samples per quarter

This reduced sampling is based on a history of no coliform bacterial contamination for at least one year prior to a request for less frequent sampling, and a sanitary survey by the Department or its authorized representative showing the water system to be supplied solely by a protected ground water source and free of sanitary defects.

The maximum microbiological contaminant levels are as follows:

a. membrane filter technique - 1 coliform bacteria/100 ml.

b. multiple tube method - coliform bacteria cannot be present in more than 10% of the portions in any one month.

When coliform bacteria are found, daily samples from the same sampling point must be collected and submitted promptly and sampling continue until the results obtained from at least two consecutive samples are shown to be satisfactory bacteriological samples.

Procedure for Collecting Water Samples

Certain steps must be followed to ensure that the water samples taken are representative of the waters to be tested and that the water samples are not contaminated during collection or before examination.

Precautions:

1. Avoid faucets that leak around the stem.

2. Remove aerators, strainers, and hose attachments before sampling. These devices can harbor significant bacterial populations.

3. Avoid taps with fluctuating water pressure. Changes in water pressure can dislodge "sheets of microbial growth" that may be located in faucet connections or in some sections of pipe.

4. Be sure the outside of the faucet is clean and dry.

Sampling Procedure:

1. Take the water sample from the cold water line.

2. It is recommended (but has not been determined to be absolutely necessary) to flame the mouth of the sample tap of the faucet with a Butane torch or other heating device. (This will destroy any bacterial growth within the tap.)

3. Allow the cold water line to run for 2-3 minutes. When taking the sample, hold the bottle in one hand and the cap in the other hand. Keep the bottle cap right side up (threads down) and do not lay the bottle cap down or touch the inside of the cap. Do not contaminate the sterile bottle with your fingers or permit the faucet to touch the inside of the bottle. Do not rinse the bottle. Sample bottles contain sodium thiosulfate crystals which are used to neutralize chlorine in the sample.

4. Fill the bottle to the top of the label and replace bottle cap.

Once again, if the laboratory finds coliform bacteria in the sample, daily samples from the same sampling point must be collected and submitted promptly and sampling continued until the results obtained from at least two consecutive samples are shown to be satisfactory bacteriological samples. Some labs automatically send out two re-check sample bottles. If you don't receive two re-check bottles in a few days, notify the laboratory.

If the presence of coliform bacteria is confirmed by a check sample, a source of contamination exists. This source of contamination should be located and measures must be taken to correct the problem. After the problem is corrected, the system should be disinfected. Additional samples are then necessary to make sure the contamination has been eliminated. For advice concerning possible sources of contamination or disinfection procedures, please contact your county sanitarian or the Water Quality Bureau:

Water Quality Bureau
Department of Health & Environmental Sciences
Room A206 Cogswell Building
Helena, Montana 59620
Phone: 449-2406

Inorganic contaminants can have a cumulative effect on human health if consumed in sufficient quantities over a long period of time. It is therefore important that the concentration of such contaminants be low enough so someone drinking the water on a daily basis will not develop health problems.

Community surface water supplies must be analyzed for inorganic chemicals yearly while groundwater supplies need only be analyzed every three years. Because non-community water supplies mainly serve a transient population, inorganics need not be analyzed for, with the exception of nitrate, which must be tested for every three years. Nitrate, unlike the other inorganics, has an immediate adverse health effect on infants six months of age or younger--it prevents the hemoglobin from combining with oxygen and suffocation

occurs. This condition is known as methemoglobinemia or "Blue Baby" syndrome. (A list of inorganic chemicals and their MCLs can be found on a chart of all monitoring requirements located at the end of this section. The MCLs of inorganics need not be memorized.)

When the results of an initial chemical analysis indicate that the level of any contaminant (except nitrate) exceeds the MCL, at least three additional samples must be collected within one month of notification to the department to determine if the water served to the public does indeed exceed the maximum contaminant level. When the maximum contaminant level for nitrate is exceeded, an additional sample must be collected within 24 hours. The mean of the two samples will determine if the maximum contaminant level has been exceeded.

As an additional note, the beneficial and harmful levels of fluoride in drinking water should be mentioned. A fluoride content of approximately 1 mg/l in drinking water is considered beneficial toward the prevention of tooth decay. However, levels of fluoride exceeding the maximum contaminant level may cause tooth mottling. For this reason, the concentration of fluoride in drinking water should be carefully monitored.

All public water supplies using surface water (river and streams) must be concerned with the contaminant termed "turbidity". Turbidity is due to small suspended particles in the water and makes the water appear cloudy or dirty. These particles can be either organic, such as leaf mold and animal waste, or inorganic, such as clay or silt particles. From a public health standpoint, turbidity interferes with disinfection, acts as a food source for microorganisms so they can survive and prosper in the distribution system, interferes with the chlorine residual in the distribution system, and interferes with the test for coliform bacteria.

Turbidity is measured by the amount of light scattered by particles in the water. As the number of particles increase, more light is scattered and a higher turbidity reading is obtained. The measuring instrument is called a nephelometric turbidimeter and the readings are expressed in terms of nephelometric turbidity units (NTU's). The MCL for turbidity must be one NTU or less as a monthly average and an average for two consecutive days must not exceed five turbidity units. If the results of turbidity analyses indicate the maximum contaminant level of five turbidity units has been exceeded, a second sample shall be taken within one hour. The repeat sample, and not the initial one, shall be used in calculating the monthly average.

Community surface water supplies should be sampled every three years for organic chemical contaminants--pesticides and herbicides. These contaminants can cause adverse health effects if consumed over a long period of time. Groundwater supplies should be checked once initially, and then need only be checked again if specified by the state.

Community water supplies shall be analyzed every four years for radiological content using four consecutive quarterly samples or a composite of four consecutive quarterly samples for gross alpha, radium-226, and radium-228.

Chlorination Requirements

Full time chlorination is mandatory where the source of water is from lakes, reservoirs, streams, or springs. Full-time chlorination of the water in a ground water supply system must be employed whenever the record of bacteriological tests of the system does not indicate a safe water. Full-time chlorination is also mandatory for any new well in a system where the initial bacteriological tests of the well do not show a safe record with the Department for three consecutive samples taken on different days after completion and testing of the well.

Any system employing full-time chlorination shall conduct a minimum of two chlorine residual tests daily: one at the point of application and one in the distribution system. However, more tests should be performed throughout the distribution system in order to ascertain that there is an adequate chlorine residual everywhere in the system.

Reporting and Record Keeping

There are three types of reports that must be sent to the State.

1. Routine sample reports
2. Check sampling reports
3. Violation reports

Accurate and adequate records must be maintained at all water plants and for all water systems. The records of all laboratory checks and control tests should be kept on file for a period of ten years by the supplier of water and must be available for inspection by the Department or its authorized representative.

Public Notification

Any community water supply system that violates maximum contaminant levels, fails to use prescribed treatment techniques, or fails to perform monitoring or use applicable testing procedures is required to issue a notice to its users with the next water bill or by written notice if the water bill is issued quarterly or not issued at all, and repeated at no less than quarterly intervals, until corrected, and shall notify the Department within 48 hours of such non-compliance. In the case of a failure to comply with a maximum contaminant level after discovery, the supplier of water must give other general public notice in a manner approved by the Department. This notice may consist of a newpaper advertisement, press release, or other appropriate means in a manner and form approved by the Department.

Variances and Exemptions

The owner of a water system may request a variance from the regulations imposed for turbidity, chemical, or radiological quality. The owner may also request a variance from the regulations concerning control tests. The

Department of Health and Environmental Sciences may authorize a variance from a maximum contaminant level or treatment technique when:

1. The raw water sources which are reasonably available to the system cannot meet the maximum contaminant levels specified in the state regulations despite application of the best technology, treatment techniques, or other means which the department finds are generally available (taking costs into consideration).

2. The concentration of the contaminant or contaminants for which the maximum contaminant level is exceeded by granting such variance, will not result in unreasonable risk to health.

3. Within one year of the date the variance is granted, a schedule for compliance, or increments of compliance, is issued and the owner of the supply agrees to implement such schedule.

An exemption may be granted to a public water system which was already in operation when the regulations went into effect, provided that provisions 1 and 2 above apply to the particular system.

Contaminant	Sampling Frequency		MCL
	Community PWS	Non Community PWS	
Microbiological			
Coliform bacteria	one sample/mo. (minimum)	quarterly	1/100 ml (Membrane Filter) Coliform bacteria shall not be present in more than 10% of the portions in any one month (Multiple tube)
Physical			
Turbidity (Surface water supplies only)	Daily	Daily	1.0 turbidity unit (monthly av.) 5.0 turbidity units (2 day av.)
Chemical			
A. Inorganic	Yearly for surface water supplies Every three years for ground water supplies	No sampling required	
Arsenic			0.05 mg/liter
Barium			1.0 mg/liter
Cadmium			0.01 mg/liter
Chromium			0.05 mg/liter
Lead			0.05 mg/liter
Mercury			0.002 mg/liter
Selenium			0.01 mg/liter
Silver			0.05 mg/liter
Fluoride			2.4 mg/liter
Nitrate (as N)		Every 3 years	10.0 mg/liter
B. Organic (Surface water supplies only) Pesticides Herbicides	Every 3 years	No sampling required	
Radiological	Every 4 years	No sampling required	
Natural-occurring			
Man-made			

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